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DOMESTIC WATER SUPPLIES FOR THE FARM

BY

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ground Waters in the Eastern
United States," etc.

FIRST EDITION

FIRST THOUSAND

NEW YORK

JOHN WILEY & SONS

LONDON: CHAPMAN & HALL, LIMITED

1912

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Stanbope Press
F. H. GILSON COMPANY
BOSTON, U.S.A.

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PREFACE.

THE water-supply problems confronting the farmer are of vital importance. Unlike his city brother, who is provided with ample and carefully safeguarded water piped to his very sink or bath, the farmer is obliged to seek his own supply, and is compelled not only to install his own water-system but is forced to personally guard and protect it from contamination. In fact, he must be his own engineer of construction, maintenance and sanitation.

The questions he has to meet are far from simple, and, with nothing but tradition to guide him, it is inevitable that mistakes will be frequent and that farm water supplies will often be a menace to health if not the cause of actual disease and death.

It is the object of this little book to explain to the agriculturist something of both the advantages and dangers of the common sources of domestic water supplies, including surface waters, springs and underground waters, and to point out to him the danger signals and indicate the steps to be taken to safeguard his supplies.

The surface waters and springs are treated with comparative brevity, for their problems are relatively simple and familiar to the farmer. The occurrence and movements of the ground waters, on the other hand, are but hazily understood by the average farmer. It is for this reason, as well as because of the fact that such waters must necessarily be the most frequent source of farm supplies, that the ground waters and their recovery through wells are considered at such length. In a book aimed to assist the farmer the treatment must be as simple and free from technicalities as possible, and the engineer will necessarily miss in its pages

the precise and technical treatment that would be more suited to his requirements.

No originality is claimed for the greater part of the subject matter, most of which is common knowledge and has previously appeared in publications of the writer and others in the reports of the U. S. Geological Survey, especially in "Underground waters for Farm Use" (Water-supply Paper 255) from which the greater part of the illustrations and considerable portions of the text have been extracted. "Well Drilling Methods" (Water-supply Paper 257), by Isaiah Bowman, has also been drawn upon for many of the statements concerning drilling methods.

The writer ventures to hope that the discussion of the ground waters, which is based on an experience of some years in charge of the underground water investigations in the eastern United States for the U. S. Geological Survey and on field examinations in more than twenty-five different states, will serve to remove some of the obscurity and mystery which surrounds them in the minds of many agriculturalists, and will lead to a clearer understanding of the principles involved in securing and protecting farm water supplies.

MYRON L. FULLER.

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Domestic Water Supplies for the Farm

CHAPTER I.

SOURCES OF WATER.

Introduction. — The agricultural lands of the United States, constituting, as they do, almost the whole of the eastern half of the country as well as a very large proportion of the habitable areas in the West, deserve to have especial attention paid to their needs. Of these needs few are greater than that of purer water supplies. Farms, which are generally remote from towns, cities or other areas of congested population, seem to be almost ideally situated for obtaining pure and wholesome water. Unfortunately, typhoid fever, which besides its propagation by flies, is known to be transmitted extensively by means of drinking water, or by milk, vegetables and other food which has come in contact with polluted water or with vessels which have contained it, is especially common on farms, the sickness and death rate from this cause being usually considerably greater in country districts than in cities.

The problem of securing water supplies that shall be adequate in quantity and, at the same time, safe and wholesome is, therefore, one of the most vital of those confronting the farmer. Upon its correct solution health, prosperity and even life itself may depend. Fortunately, all natural waters, both surface and underground, are, except when polluted by human or animal agencies, generally safe; and, with the exception of a few sulphur and alkaline waters, are reasonably wholesome.

Rainfall in the United States. — The agricultural lands of the United States are, as a whole, blessed with a fairly liberal supply or precipitation. In the eastern half of the country the rainfall is plentiful, the yearly average varying from 20 to nearly 70 inches (see Fig. 1). Rain to a depth of more than 60 inches a year falls on the Mississippi delta below New Orleans, and along the Gulf Coast from near Mobile, Alabama, to Tallahassee, Florida. A nearly equal amount falls in the higher mountains of western

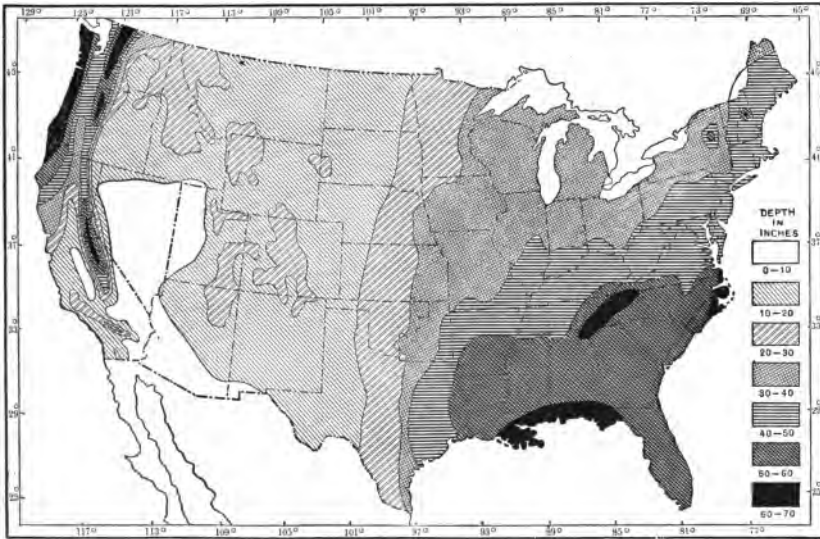


FIG. 1. — Map showing mean annual rainfall of the United States.

North Carolina, and eastern Tennessee, along the coast of North Carolina and in the Adirondack and White Mountains. In the Gulf and South Atlantic States the rainfall is between 50 and 60 inches a year; in the New England, Central Atlantic and Ohio River States, between 40 and 50 inches; in the upper Mississippi and Great Lake states, between 30 and 40 inches; and in northwestern Iowa and most of Minnesota, between 20 and 30 inches.

In the western part of the United States the distribution of the rainfall is much more irregular than in the eastern part. West-

ward from a line drawn through the eastern part of the Dakotas, middle Nebraska, western Kansas and central Texas the rainfall decreases to less than 20 inches yearly, all of the Great Plains region being characterized by small rainfall. In the Black Hills, the Bighorn Mountains and the higher sections of the main chains of the Rocky Mountains the rainfall is 20 or 30 inches yearly; and in the high Sierra, the Cascades and the Coast Ranges it is 70 inches or more, reaching a maximum of 150 inches in the Coast Ranges of Oregon. In the Great Basin region, between the Sierra Nevada and the Wasatch Mountains, the rainfall is less than in any other section of the country, in places being as low as 2 or 3 inches a year.

Run-off. — Only a small part of the precipitation on most areas is disposed of directly by run-off, by far the greater part of the flow of the surface streams being supplied by waters that have first been absorbed by the ground, rather than by waters shed directly from the surrounding slopes. In arid regions, where the surface deposits are porous, the run-off is relatively small, but, owing to the fact that rain in these regions falls chiefly in sudden downpours, the annual run-off is not so small as would be indicated by the small annual precipitation. In humid regions and in places where the surface is composed of impervious materials the run-off is greater. Frozen, snow-covered and ice-covered ground yield especially large flood flows. Over frozen areas nearly all the rain water may at once join the streams, whereas in some sandy regions practically all the precipitation is absorbed by the soil. In the eastern half of the country the run-off will probably not average more than 20 per cent of the rainfall. In the West, although the percentage of run-off in small areas is at times great, it is on the whole less than in the East, for much of the water that is not taken up directly is later absorbed from the streams by the dry, sandy soils.

Evaporation. — Owing to the great humidity of the atmosphere during storms, evaporation while rain or snow is falling is small. Snow may remain on the ground a long time, and, as a rule, is

evaporated to a greater degree than rain, especially during periods of sunshine and warm winds that follow storms. The evaporation from different areas also differs greatly. From forest-covered soils it is relatively small; from open plains it is relatively large.

Absorption. — The rain water that is not evaporated immediately or carried off by streams sinks into the ground. The ground receives the greater part of the rainfall, probably nearly 80 per cent in the eastern United States and 90 or 95 per cent in much of the West. Absorption by the underlying rocks takes place both directly and indirectly. Rain may fall on the surface of the rocks and be absorbed in their pores, fissures and cavities; or it may be first absorbed by loose, unconsolidated surface deposits and afterwards carried down into the rocks, or it may be gathered into streams that flow over rock surfaces and from these gradually absorbed by the underlying rocks. The amount of rainfall that the rocks absorb indirectly is far greater than that which they absorb directly.

Water that enters sands and gravels generally moves toward the streams rather than away from them, but in regions where the rainfall is small the gravels may absorb water from the streams which rise in regions of greater rainfall.

Recovery of Natural Supplies. — Of the surface waters ponds and lakes are directly available as sources of water supplies, and streams may be made so by the simple process of impounding the waters by dams. The waters of springs may likewise be collected in reservoirs and distributed as desired.

The recovery of ground waters presents more difficulties. Not only must wells be sunk, often to great depths and at heavy expense, but pumps and even power must usually be provided for raising the water to the surface, the only exception being those artesian wells whose waters are under sufficient head to bring them to the surface and give rise to natural flows.

Sources of Farm Supplies. — The sources of the water used on the farm are numerous — lakes, streams, springs, drilled, bored,

driven and dug wells and cisterns all being extensively used, although the water from lakes and streams is generally used only for stock. Each of these sources under some conditions may yield entirely safe and satisfactory supplies, while under other conditions certain of them may be a constant menace to the health. Of the various sources mentioned the ground water is on the whole the most satisfactory for farm use, because it is least liable to pollution, and streams and ponds are the most unsatisfactory, because of the ease and frequency with which they are contaminated. Fortunately, however, the latter are very seldom used for drinking and domestic purposes, being utilized mainly for stock, on which the effect of moderate pollution is not apparent. The underground supplies, whether from wells or springs, although safe in many localities, are far from being universally so, the safety depending mainly on their location and on the nature of their protection. These are discussed in the following sections.

CHAPTER II.

SURFACE WATERS.

Sources. — Under surface waters, as the term is here used, are included those waters which occupy basin-like depressions in the surface, giving rise to lakes and ponds, or flow as streams down its valleys. The waters of such lakes and streams do not represent simply the collected rainfall from the surface, by far the greater part coming, as a matter of fact, from the ground and representing the surplus precipitation which was first absorbed by the soils and rocks and later set free to swell the surface drainage.

Springs are intermediate between ground water and surface supplies, and are classed sometimes with the one and sometimes with the other, according as the ground water origin of the supply or the surficial situation of the spring is considered as most significant. In the present discussion they are considered in a chapter by themselves.

Besides the natural surface-water bodies, which include the lakes, ponds, pockets and "tanks" on the one hand and the brooks, streams and rivers on the other, there are the artificial pools, ponds, and reservoirs, all of which, under certain circumstances, are in common use as sources of farm supplies.

Lakes. — The waters of lakes, which here include all fresh-water bodies a mile or more in diameter, are generally good, except when they are polluted by the drainage or sewage from cities or large towns on their shores or on the lower courses of tributary streams. In ponds and in the smaller lakes such pollution may render the entire body of water unsafe for domestic use.

Sunlight, however, has a marked purifying action, tending to destroy the dangerous germs, while, under the action of winds, wave action and circulation are induced in the water, favoring aeration (mixture with air), which, by oxidation, likewise helps to

remove the dangerous impurities. At the same time the heavier sediment brought in by the streams is constantly settling to the bottom. As a result of all these processes of purification the water which entered in a polluted state may at last become so changed that on leaving the lake at its outlet it is both palatable and wholesome.

So rapidly has this purifying action been supposed to take place that before the construction of the Chicago drainage canal it was thought safe by some to draw the supply of the city from Lake Michigan at a distance of only a few miles offshore. Experience proved, however, that while noticeable pollution was confined to a relatively small portion of the lake, and while normally the city supply was fairly safe, it was, nevertheless, under certain conditions of wind and currents, liable to pollution. It was thus necessary either to remove the intake to a point several miles farther away or to divert the sewage from the lake. The Chicago drainage canal, by diverting the sewage, has done much to solve the problem.

Natural lakes are confined almost wholly to the northern portion of the country, where they form a belt extending from eastern North Dakota to eastern Maine. In this belt, besides the Great Lakes, there are tens of thousands of smaller lakes, Minnesota alone having several thousand.

Most of the lakes, especially the smaller ones, are in thinly inhabited regions and afford supplies of high purity. Unfortunately, however, owing to the fact that farmhouses, even if in the vicinity of lakes, are usually placed on high ground at some distance from the water it is necessary, if the lake is used as a source of supply, to haul the water required for domestic purposes. Because of the inconvenience thereby entailed few of the lakes are used, although they constitute ideal supplies for horses and cattle and furnish pure water to those cities which lie within convenient piping distance from them.

Ponds.— In the smaller water bodies, varying from mere pools to lakelets several acres in extent, there is less dilution of the

impurities washed into them than in the lakes and large ponds, and even where there are both an inlet and an outlet there is often a tendency for the main current to pass directly from the inlet to the outlet without mixing with the water as a whole, the greater part of the lake thus remaining relatively stagnant. The entrance of a very slight amount of polluting matter into such waters may dangerously affect their quality.

Owing to the slight circulation in these small bodies of water decaying leaves and twigs will frequently accumulate and, together with the growth of water organisms, will give the water an amber or even a dark-brownish color and a noticeable taste. Such coloration does not make the water dangerous any more than the green algal slime that collects on the surface (most of which is perfectly innocent), but both are indications of stagnant conditions that are repugnant to the mind and may mask dangerous impurities. On the bottoms of ponds of this sort there are usually accumulations of decaying vegetable matter mixed with silt, which are very objectionable in water to be used for drinking. It is such accumulations which give off the bubbles of gas that may be seen rising to the surface when the bottom is disturbed.

Not all small ponds, however, should be condemned because of their size. Many are fed by springs, are free from pollution and contain water as clear and cool as could be desired. Such ponds may be used to advantage for domestic supplies, although as the farmhouses are usually situated at a distance from the water they are seldom used except for watering stock.

Many of the water pockets or " tanks " of the deserts, in part natural and in part artificial, are also entirely unsafe even for stock use, although as they constitute the only source of water in many regions such use is unavoidable. In fact, the upbuilding of considerable grazing industries has been made possible by such water pockets in otherwise waterless regions.

Artificial Ponds, etc. — In some of the prairie and semi-desert regions, where streams are relatively few in number or even absent over large areas, and where wells do not yield sufficient

supplies, water is often obtained from artificial ponds. These are usually formed by throwing up a low embankment across some shallow depression or flood-water channel, behind which the rain water or the brief flood flow accumulates. Such reservoirs are commonly but a few rods in diameter and a few feet in depth. As a consequence the water becomes heated in summer, is usually kept constantly muddy by the movements of stock, and is highly polluted by them. (See Fig. 2.) As numerous animal diseases may be communicated through drinking water, small ponds of this sort may become a source of great danger.

In hilly regions it is often possible, by erecting a short dam across some small valley or ravine, to pond the water of some spring or brook, forming a small reservoir from which the water may often be piped to the farm buildings below. If the spring or stream furnishing the supply is protected from cattle, from wash or seepage from pastures, roads, and barnyards and from sources of human pollution, such reservoirs will often provide admirable supplies. This is especially true of the farms in valleys bordered by wooded hills such as abound throughout the Appalachian Mountains of the East and the larger mountain systems of the West.

Streams.—Over a large part of the country streams and rivers form the most available sources of supply, and in thinly settled regions they are usually free from contamination, although even here a tan-bark plant or sawmill may lessen the desirability of the water for domestic purposes.

Mines, especially coal mines, may likewise discharge their drainage of acid and otherwise polluted waters into the streams with similar effects, but the most common source of pollution is the sewage from towns and cities. In fact, practically all the larger streams, and even many of the smaller ones, are highly polluted by such sewage or by refuse from various manufacturing plants. It is true that such streams become gradually purified and under ordinary conditions may be fairly safe, but the periodic outbreaks of typhoid fever that occur among the users of their

water are sufficient to indicate the imperfect nature of this purification.

Large cities without other accessible sources will doubtless continue to use river waters, but these waters are now, as a rule, scientifically filtered before distribution. On most farms, however, other and safer sources are available, and stream waters which are known to have received drainage or sewage from any source should not be used for drinking. (See Fig. 3.) In the larger streams the pollution is rarely high, and many of them will afford satisfactory supplies for stock.



FIG. 2. — Pollution of pond by stock. (Photo by U. S. Geological Survey.)



FIG. 3. — Pollution of stream from outhouses. (Photo by U. S. Geological Survey.)
(11)

CHAPTER III.

SPRINGS.

What a Spring Is. — The term “spring” is properly applied to the water emerging from the ground at a single point or within a restricted area. The distinction between springs and general seepage, however, is not always very sharp, for there are all gradations between the concentrated outflows characterizing true springs and the diffused emergence of water over large areas or beneath the level of the water in streams.

In size springs vary from the little pools only a few inches across and barely overflowing their tiny depressions to immense basins like that of Silver Spring in Florida, which is navigable by steamboats and gives rise to a river several rods in breadth.

In manner of emergence there is likewise a wide divergence. By far the greatest number of springs probably emerge in the beds or banks of streams or ponds, but they are inconspicuous and often almost unsuspected. The base of steep bluffs is also a favorable point for the emergence of the ground water, and is often dotted with a line of springs. Springs are by no means confined to such situations, however. Many boil up through the soils of perfectly flat plains, while others gush forth as cascades from the rocks. (Fig. 4.)

Allied to the springs, and often classed with them, are the underground streams that sometimes flow forth in limestone regions from the subterranean caverns. Some are almost rivers in size. A good example of a subterranean stream of this sort is shown in Figure 5.

Source of Water. — The water of all springs is of subterranean origin, the supply coming from the great underground water body fed by precipitation falling upon and absorbed by the soil and rocks. The greater part of the water is naturally from shallow

sources, much of it from the superficial soil, but considerable quantities come from deeper sources, perhaps from hundreds of feet down in the rocks.

Kinds of Springs. — Springs may be divided, according to their mode of origin, into gravity and artesian springs, and, according to the nature of the passages traversed by the water, into seepage, tubular and fissure springs.

Gravity Springs. — A gravity spring is one whose water is not confined between impervious beds but flows from loose materials

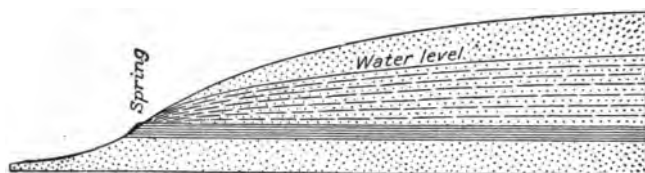


FIG. 6. — Spring of gravity type fed from unconfined waters in porous sands.

or open passages under the action of gravity, just as a surface stream flows down its channel. The conditions are shown in Figure 6.

Artesian Springs. — An artesian spring is one whose waters are confined in impervious channels or between impervious beds and are under hydrostatic pressure because the water level at their source is higher than the point where they emerge. The waters of such a spring, if confined in a pipe instead of being allowed to flow out upon the ground, may rise considerably above the spring mouth. (Fig. 7.)

Seepage Springs. — Seepage springs are springs in which the water seeps out of sand or gravel; they differ from general seepage only in being restricted to a small area. Such springs are usually marked by abundant vegetation at their points of emergence, and their waters are often colored or carry an oily scum due to the decomposition of vegetable matter or the presence of iron. The scum is frequently mistaken for petroleum. The waters of the seepage springs commonly come from no great distance beneath the surface and are not usually very cold.



FIG. 4. — Spring from bedded limestone. (Photo by U. S. Geological Survey.)



FIG. 5. — Subterranean stream in limestone. (Photo by U. S. Geological Survey.)
(15)

Seepage springs may emerge along the top of an underlying impervious bed, but more commonly they occur where valleys are cut downward into the zone of saturation of a more or less uniform water-bearing deposit. Under favorable conditions the seepage from sands, as on Long Island, New York, gathers into channels and forms streams of considerable size, some of them flowing 5,000,000 gallons or more daily.

Seepage springs, as in the cases cited, are commonly of the gravity type, but where channels or fissures emerge beneath beds of sand or gravel seepages not infrequently result from true artesian springs.

Tubular Springs. — Tubular springs embrace a great variety of flows, including both those in the small more or less tubular passages in the drift and those occupying large solution channels or caverns in the soluble rocks.

The channels of springs in the drift are generally established along some more or less sandy or other porous layer, or perhaps along the path left by a decaying root. The motion at first appears to have been mainly that of seepage, but in many springs a passageway has been gradually opened, along which a definite stream finds its way. The waters reach the channels by percolation through the clays and sands and are usually free from pollution except when near cesspools or vaults sunk some distance into the ground.

In limestones and other soluble rocks the underground passages may reach many miles in length. Single passages, as in the Mammoth Cave of Kentucky, have been traversed for a distance of many miles, and passages several times as long, though as yet undiscovered, probably exist. Some of these passages are many feet in diameter and are traversed by streams of considerable size, or even by rivers. The Silver Springs of Florida give rise to a river which is navigable from the ocean to its source in the springs, and springs of similar volume occur at other points in Florida and Arkansas and possibly elsewhere. The waters of such springs vary greatly in composition, although most of them

are hard. In some springs the waters are exceedingly clear, the bottoms being distinctly visible at a depth of many feet, but in others the waters are muddy after severe storms. When clear it is probable that the waters feeding the underground stream reached it by percolation through the porous earth or rock, during which its impurities were largely removed. Where muddy the waters in part appear to have penetrated downward through sinks or to have entered the rock directly as streams; in either case they are very liable to pollution by impurities washed in with the water.

Tubular springs are most commonly of the gravity type, the channels generally sloping from higher to lower levels. In both drift and limestone, however, there are numerous exceptional springs whose channels are at some points in their courses considerably lower than their outlets. Under such conditions the water may be under considerable artesian pressure in the lower parts of its channel or even at its outlet.

Fissure Springs. — The term fissure spring is here used rather comprehensively to include the springs issuing along bedding,

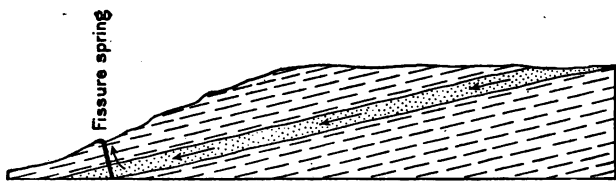


FIG. 7. — Fissure spring (artesian type).

joint, cleavage or fault planes. (See Fig. 7.) The distinguishing feature is a break in the rocks along which the waters can pass, it being immaterial whether any considerable open space exists. These springs differ from tubular springs in that they are as a class of deeper-seated origin, as is attested by their temperatures. The waters are almost never subjected to contamination, though in many springs they are highly mineralized. Springs of this class are often distributed along straight lines for considerable distances, their position being determined by lines of fracture or jointing.



FIG. 8. — Pollution of ground water by sewage discharging into sink hole.
(Photo by U. S. Geological Survey.)



FIG. 9. — Dairy spring from polluted underground stream. (Photo by U. S. Geological Survey.)

Importance of Springs. — Springs usually form an ideal source of farm supply. Occurring in great abundance in many of the thinly settled regions and coming from considerable depths within the rock or filtering from sand or gravel, they are almost always free from pollution except where buildings are situated on the hillsides above them or where surface wash is allowed to enter them.

In the more hilly regions, such as those of New Hampshire and Vermont, especially where the farms lie in the valley, the water from hillside springs can usually be piped with little difficulty to the house and barn, where it flows as a steady stream under the influence of gravity alone. A farm supplied from such a source is fortunate indeed. Hydraulic rams are often successfully used in lifting spring waters to buildings high above their source.

Safety of Springs. — Natural spring water is almost never dangerous to health, as the minerals it contains in solution are generally harmless, although a few waters act as a physic and others may contain sulphur gases in disagreeable amounts.

Springs from sands, sandstones, clays, shales and slates are seldom polluted, except where contaminating matter penetrates through cracks or fissures, or through the material itself where the covering above the water is very thin. Usually such pollution is likely to occur only where houses, barns, sewers or cesspools are located on higher ground near the spring, or more especially where cities or towns are so located. In limestones, on the contrary, sewage or other polluting matter frequently enters the underground channels through the sinks (Fig. 8) and may contaminate the underground water for long distances. Similarly in the tubular channels in the till, if material from a cesspool or other source of pollution finds access, the water may retain its contamination for a long period and a great distance.

Tests for Pollution. — There is no infallible chemical test for the detection of pollution in small amounts. If a chemist is thoroughly familiar with the normal character of water in the immediate vicinity he may be able to detect contamination by

means of chemical examination; but waters contain so many harmless substances dissolved from the earth that the determinations by a chemist are often inconclusive. Careful observation of the spring itself and a common-sense inspection of its surroundings are usually of more value than an analysis. The spring should be protected from pollution, especially from surface drainage from houses, barns, hogpens and other outhouses that are situated on the slopes above it within a distance of several hundred feet. When the absence of such local sources of pollution is established the water should be carefully watched, especially in limestone regions, for muddiness or floating matter rising with the water after severe rains. Such phenomena are evidence of connection with sink holes and indicate that the water is to be looked upon with grave suspicion if opportunity exists anywhere within miles for the entrance of polluting matter through sinks or otherwise. Figure 9 shows a spring in Greene County, Missouri, used for dairy purposes. The spring is remote from buildings and the water is clear, cold and sparkling, but is, nevertheless, more or less polluted, owing to the fact that the underground stream feeding the spring appears at the surface at a number of points above it, crossing one or more highways and receiving the drainage from them and from a cemetery.

Protection of Springs. — One of the most common causes of contamination of springs in the farming districts arises from failure to fence the springs to prevent the access of stock. Figure 10 shows a mineral spring in Georgia from which many people drink and from which the waters have at times been shipped, but about which stock are nevertheless allowed to roam freely, drinking from it at will and incidentally contaminating it in a variety of ways. It is needless to say that any spring used for drinking water should be carefully fenced at such a distance as to prevent any excrement from reaching it.

The spring mentioned above is located only a few inches above the bottom of the stream channel shown on the right of the view. When the picture was taken no water was flowing in the channel,



FIG. 10. — Spring receiving pollution from stock. (Photo by U. S. Geological Survey.)



FIG. 11. — Spring receiving wash from fertilized land. (Photo by U. S. Geological Survey.)

but at times of rain considerable volumes of water descend along the depression, covering the spring and washing into it all sorts of refuse from the hillsides above. Figure 11 shows another spring, located in Missouri, receiving the drainage from a cornfield, together with such manure or other fertilizer as may be used in the cultivation of the crops. This water, which carries both sulphur and Epsom salts, is considered of medicinal value, but it is clear that, situated as it is, its safety is at least doubtful.



FIG. 12.—Polluted spring in center of city street. (Photo by U. S. Geological Survey.)

In general, it is not advisable to use springs for drinking water where their location normally exposes them to inflows of surface drainage. If other sources are not available, however, the spring should be carefully protected by impervious walls, which should be carried to sufficient height to keep out the surface water.

Another source of frequent and objectionable though not necessarily dangerous contamination is the leaves, paper, dust and dirt blown into open springs by the wind.

An example of danger from refuse of a more disgusting type is shown in Figure 12. Located in the middle of a well-traveled street, only a few inches above a gutter filled with paper and refuse, a part of which is sure to enter whenever a heavy rain occurs; open to the rain which washes into it from the steps leading down to it such dirt from the street as is brought in by the feet of the users; subject to the dipping of all sorts of more or less dirty buckets and utensils; receiving the underground drainage and presumably more or less sewage from the buildings on the slopes above; and containing in its bottom several inches of decaying paper and other refuse, this spring is on the whole one of the worst and most dangerously located sources of drinking water in the United States.

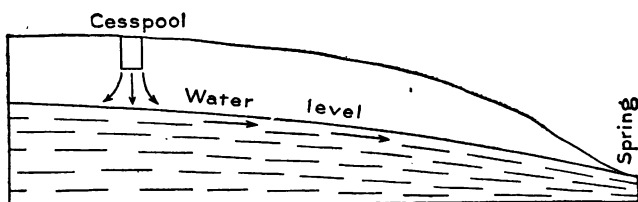


FIG. 13. — Diagram showing manner in which springs may be polluted by subsurface drainage.

In farming districts pollution by subsurface drainage from buildings on the slopes above the springs is not very common, although many springs are located back of barns, below hogpens and outbuildings. The placing of buildings above springs intended for use should always be avoided, even if the spring is several hundred feet away from the proposed site. (See Fig. 13.)

Protection of Sink Holes. — It has already been pointed out that much of the water in limestones, the springs of which are frequently used for drinking and domestic purposes, enters the rock through open sink holes, into which in some places manure and other refuse has been dumped or sewage drained. Figure 8 shows a small but continuous stream of sewage from a large college building discharging into a sink from which it finds its

way to the underground water channels. Such practices are very dangerous. Cases of typhoid fever have resulted from drinking water from springs or wells which have become polluted by such matter entering the sinks; and, even where specific pollution is absent, undesirable slimes and rubbish often render the water highly objectionable. Instead of discharging refuse or sewage into sinks every care should be taken to protect them against its access.

Piping of Springs. — Spring water should always be conveyed by iron pipes, as lead, which was formerly much used, is more or less readily dissolved by soft waters. Thousands of cases of lead poisoning resulted from such use in Europe and America before the cost of lead pipes became so high that they were largely abandoned.

Where the water flows continually there is little danger from lead pipes, but if the flow is shut off when not in use, enough water should be drawn off each time to remove entirely that which has been standing in the pipes before taking any for domestic purposes or for the use of stock.

Another precaution to be taken in piping springs is to lay the pipe well below the winter frost line in order that there may be no interruption of supply nor breaks due to freezing. The depth will vary greatly in different parts of the country, being as much as 6 feet in some of our northern states, while a few inches would be a sufficient depth in much of the South.

CHAPTER IV.

GROUND WATERS AND THEIR OCCURRENCE.

Derivation of Ground Waters. — Practically all of the water in the soil and rocks is of meteoric origin; that is, it is derived from rainfall. In fact, many who have written on underground waters have stated that rainfall is the only source of supply. In reality, however, while rainfall probably contributes at least 99 per cent of the total subterranean water, there are several other possible sources of such water.

Of the small percentage of water derived from sources other than rainfall a small quantity is "magmatic water," or that given off by molten rocks (magmas) at great depths; but, although considerable additions may be made locally to the underground water body in this way at points of igneous activity, the additions to the supply in the earth's crust as a whole are insignificant.

It is also a well-known fact that along coasts of unusually porous materials such as certain coarse sands and coral or other porous limestones, especially when the rainfall is light, the sea water may penetrate through the pores of the rocks for a considerable distance inland; but, the amount, although somewhat greater than the magmatic waters, is very small.

The greater part of the non-meteoric waters appear to represent sea waters included in marine foundations that have been subsequently uplifted and converted into land. By far the larger portion of the sedimentary deposits, including sandstones, shales, limestones, etc., were originally laid down along the borders or beneath the surface of the ocean, and were, of course, originally saturated with salt water. It is probable that this water was often retained in the materials when they were uplifted and con-

solidated into rocks, and is represented by the salt waters now found at great depths in the deep wells drilled for oil or gas, in which it is not uncommon, after passing through hundreds of feet of entirely dry rock, to suddenly encounter porous beds filled with salt water.

Absorptive Capacity of Soils and Rocks.—The absorptive capacity of soils and the more porous rocks is enormous. As pointed out elsewhere 80 per cent of the rainfall is probably absorbed by the soils and rocks in the eastern United States and over 90 per cent in much of the West. The greater part of water so absorbed reappears at the surface as seepages and springs to form the streams or feed the ponds and lakes, usually within a few weeks or months of the time it fell upon the surface, although a part may join the deeper waters and reappear at the surface only after years or even centuries of imprisonment in the subterranean depths.

The amount of water in several of the more common classes of rocks is discussed elsewhere, but a statement of the common porosities or the percentage of volume occupied by water when the soil or rock is saturated is given below.

POROSITY OF SOILS AND ROCKS.

	Per cent.
Soil and loam.....	55
Clay.....	50
Sand.....	30
Chalk.....	50
Sandstone.....	10
Limestone and marble.....	4.5
Slate and shale.....	4
Granite.....	1
Quartzite.....	.5

The actual amount of water in the rocks will in most cases be slightly in excess of that indicated by the porosities, since very appreciable quantities also occur in the more or less open passages such as joints, bedding planes, etc., while in limestones considerable amounts are often present in solution channels.

Total Water in the Ground. — The question of the amount of free water in the ground is of much interest to drillers and those seeking supplies. By free water is meant water in its ordinary liquid form. It does not include the chemically combined water of certain minerals and rocks, but is the water that occupies the pores, joints, solution passages or other openings.

Several attempts have been made in both Europe and America to estimate the total amount of such water in the earth's crust, but with varying results. Delesse, in France, estimated the amount as sufficient to make an envelope of water 7500 feet in thickness. Slichter, in America, placed the amount as equivalent to a sheet 3000 to 3500 feet thick. Van Hise's estimate for the continental areas was a sheet equivalent to 226 feet, while Chamberlin and Salsbury estimated the amount as equivalent to a layer 1600 feet in depth. In all four cases, however, the estimates were based wholly on certain theoretical assumptions, several of which are now known to have been incorrect. An estimate by the writer, based on a wide study of the actual conditions in thousands of wells and scores of mines, combined with revised theoretical data, places the estimate at a little less than 100 feet for the equivalent thickness of the ground water body in the earth's crust as a whole. It must be understood, however, that locally the amount is likely to be several times that stated, while elsewhere nothing but practically dry rocks will be penetrated from the surface downward.

Methods of Absorption. — The amount of water which enters the rocks or other materials by direct absorption varies greatly with the nature of the materials. The amount absorbed by the porous beds of sands and gravels that occur along stream valleys and along lake shores and the coast is very large. In some regions, as in portions of Cape Cod and Long Island, there are practically no surface streams, the water being permanently absorbed by the soil as soon as it falls and carried to the sea by underground drainage.

Next to unconsolidated deposits the rocks which present the

conditions most favorable for direct absorption are the sandstones and certain of the porous limestones. In the case of the granites, slates and other massive rocks the direct absorption is very slight.

Besides the character of the material the amount of absorption depends very largely upon the inclination of the porous beds, the amount being much greater in the gently inclined beds than in those having steep dips. Thus in Figure 14 the two beds represented as outcropping on a level surface present widely different absorptive



FIG. 14. — Relation of areas of outcrops to dip.

conditions owing to the difference in area of their absorptive surfaces, the exposed surface of the gently sloping bed ($a' - b'$) being several times greater than that of the highly inclined bed ($a - b$).

The quantity of water absorbed by rocks that are directly exposed to the falling rain is slight in comparison to that taken up by those covered with coatings of soil, loam or sand and gravel. Such materials take up the rain as would a sponge and keep the water in constant contact with the underlying rock surface, by which it is slowly absorbed, instead of running off as does the main portion of the precipitation falling on the bare ledges.

Waters from Lakes and Streams. — One of the most common popular conceptions is that ground waters are derived either from neighboring or from more remote lakes and streams. It is too well known to require more than the simple statement, however, that the movement of such water is normally toward and not away from the water bodies, the surfaces of which are below and not above the water table. It is only when there is some sudden rise of water in the lake or stream due to causes independent of local rainfall that the level becomes higher than the adjacent water table and a landward movement takes place. These conditions are illustrated by Figure 15. Such movements occur

temporarily during the flood period of rivers fed from mountain snows, etc., or in lakes supplied by such streams. Similar conditions exist where the torrents resulting from cloud-bursts temporarily flood certain parts of our great deserts.

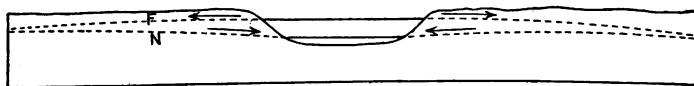


FIG. 15. — Section illustrating conditions governing movement of water away from streams or lakes. N, Normal position of water table; F, position of water table during floods.

Underground Waters and Mountains. — There is also a widely prevalent belief held by the inhabitants of lowlands that the ground waters, especially the deeper supplies, come from distant hills or mountains. Where true artesian conditions exist, such as described in Chapter VIII, there is a possibility that the waters may have originated in the manner indicated, being absorbed by the outcropping edges of the formations in the distant highlands. Such is the case of the deep waters of the Atlantic Coastal Plain, of those of the High Plains which stretch outward from the base of the Rockies to the east and of the waters of the innumerable basins among the western mountains and in the gravel and wash plains at their base.

In the great majority of localities, however, no such relation of the ground water to mountains exists, even in the case of the deeper waters, since neither the geological formations nor the water bearing passages, such as joints, solution channels, bedding plains, etc., are continuous for any great distances. In fact, not only the shallow waters but the deep waters as well, are commonly of relative local origin, being in most instances absorbed by the soil or rocks within a few miles of the well, or within 50 or 100 miles at the outside.

Underground Rivers. — “Underground rivers” often figure conspicuously in the popular mind, the conception being, in many cases, of vast streams flowing majestically through the earth far below the surface, much like the streams of the surface. Under-

ground streams are not entirely mythical, although few are of a size that would lift them to the dignity of rivers. Instances are numerous in limestone regions where streams several feet, or perhaps a rod or more in width, flow through underground channels, are joined by tributaries, plunge over ledges as waterfalls, and, in fact, behave much like surface streams. Such a stream is shown in Figure 5.

Outside the limestone regions there is, in general, no moving ground water of a size to warrant the term river. The entire ground water body, as explained elsewhere, is in motion, but the movement is slow, often but a few inches a day, and the movement is that of a sheet of water rather than an underground "river."

In places, nevertheless, where porous materials lie between masses of unporous materials, as in the case of gravels lying between the granite walls of valleys, etc., the motion is more rapid — perhaps several feet a day — and a sort of sluggish stream may slowly push its way through the soil. Nothing of the nature of the free flowing stream of the limestone regions exists, however.

Underground Lakes. — There is little to warrant the common belief in the existence of "underground lakes." A few small pools are found in limestone caverns, but in the great majority of soils and rocks the water occurs only in the pores or occupies minute fissures or other parting plains.

In the more porous materials, however, especially in sand and gravel, the volume of water is often very large and is given up freely to wells. This, and the fact that the water is commonly struck everywhere at about the same depth gives rise to the belief of an underground lake with a definite upper surface, a conception that is not far from the truth, except that the water exists not as a free body but as a body filling the pores of the sand or gravel as it would a sponge.

Temperature of Underground Waters. — In all wells there is a certain depth, which differs in different localities, at which there is practically no difference in the temperature of the water from

season to season or from year to year. This is known as the normal temperature of the water for a given region, and it agrees very closely with the mean annual temperature of the same locality. The depth of uniform temperature varies somewhat in different localities, but is commonly from 50 to 60 feet below the surface. The temperature varies from about 40 degrees or 45 degrees in New England to about 65 degrees to 70 degrees in the Gulf States.

Waters occurring nearer to the surface than the zone of uniform temperature vary in temperature according to season, being warmer than the normal in summer months and colder in the winter months. The temperature of waters warmer than the normal may also be due to the great depth from which the waters have come.

The main cause of rise in temperature below the line of invariable temperature is the internal heat of the earth. This internal heat increases rapidly downward, the rate of increase varying from 1 degree in 30 feet to 1 degree in 100 feet, the average increase being about 1 degree to 50 feet. The temperature of the water is very little affected in passing through the upper 50 feet of its course, hence its temperature is a fair indication of the depth from which it is derived.

Besides the internal heat of the earth the heat of igneous masses below the surface of the earth has been thought to give rise to the hot springs of many localities, and in some instances the heat evolved by the chemical decay of rocks has been cited to explain the temperature of hot springs.

CHAPTER V.

WATER-BEARING FORMATIONS.

Classes of Rocks. — All known rocks contain more or less water, and though many of them will not yield it in useful quantities to wells all must be considered in a discussion of water-bearing formations. Many rocks are familiar to everyone, at least by name; others are less widely known and may be restricted to very small areas. The classes of rocks commonly recognized and the definitions of the simpler varieties are given below for the benefit of those not familiar with the terms in use.

In a simple classification rocks may be grouped into three divisions: (1) sedimentary, (2) igneous and (3) metamorphic.

Sedimentary rocks are formed either of fragments worn from older rocks by the action of rain, wind, frost, etc., and carried by water, wind or glaciers until deposited as beds of clay, sand, gravel, marl, loess, etc.; or of the remains of corals or of shellfish, such as oysters and clams. When first deposited the materials are loose and unconsolidated, but gradually they become hardened and cemented together, especially when covered by later beds, and eventually form solid rocks. These fragments or grains are commonly rounded, and their form may therefore help to distinguish them from igneous rocks, which may have corners or angles or may include angular crystals.

Igneous rocks may have come from the earth's interior in a molten state and have been forced into or through the rocks above them or may have overflowed as lava beds at the surface. They are generally made up of or at least include angular crystals, which may be recognized by their glistening faces, a feature that is not usually possessed by sedimentary rocks. Many of

them are banded and most of them are irregular in mass and occurrence; locally they may contain vividly colored patches and bands.

Sedimentary and igneous rocks in many places have been subjected to heat and pressure after their deposition. This action may have further hardened them or have so greatly changed them that their original character can scarcely be determined. Rocks thus changed are known as metamorphic rocks. Mica schist and marble are typical examples. As a rule they exhibit a bedded or banded structure.

Rocks of all of these types occur the world over, and those of one locality may be indistinguishable from those of another. Notwithstanding these similarities, they may have been formed under very different conditions and at periods thousands or even millions of years apart. Resemblances between rocks do not, therefore, mean that they were formed at the same time or will yield the same products, such as coal or oil or water.

Simple definitions of the more common rocks are given below. Complete descriptions and definitions of rarer varieties may be found in any text-book on geology.

Unconsolidated Sedimentary Deposits. — Gravel, sand and clay are made up respectively of pebbles, sand grains and fine silts worn from older rocks and redeposited in their present form.

Alluvium is a general term for gravels, sands and clays, or mixtures of these that have been deposited by streams.

Chalk is a soft white earthy form of limestone.

Marl is a clay with much intermingled calcareous material.

Till is a heterogeneous mixture of clay, sand, pebbles and boulders deposited by glaciers.

Hardpan is a general term which may be applied to any bed which is considerably harder than those with which it is associated. It is often applied to till, to tough clays or to partly cemented sand or clay beds.

Consolidated Sedimentary Rocks. — Conglomerate is a consolidated gravel.

Sandstone is a consolidated sand. It is said to be massive if there are few bedding planes, and shaly if it splits into plates.

Quartzite is a sandstone in which the spaces between the grains have been filled with a hard cement (silica), forming an excessively hard rock.

Shale is consolidated clay; a soft, fine-grained rock which tends to split into thin plates. It is sometimes improperly called soapstone.

Limestone is composed mainly of carbonate of lime, but often contains sand and other impurities, and may be very hard. Not infrequently it contains many shells or is made up entirely of them. It can be most readily recognized by the bubbling which takes place when it is touched with hydrochloric (muriatic) acid. In varieties high in magnesia and in magnesium carbonate (dolomite), hot, strong muriatic acid is necessary to produce this action.

Tuff is any sedimentary rock that is made up entirely or almost entirely of fresh fragments of volcanic rocks.

Concretions are hard, lumplike masses within the rock. They should not be confounded with real boulders, from which, as a rule, they may readily be distinguished, because they consist of nearly the same material as that in which they are embedded.

Igneous Rocks. — Granite is a wholly crystalline rock, composed of quartz, feldspar and other light-colored minerals.

Diorite, gabbro and diabase are crystalline rocks similar to granite, but with less quartz and with dark-colored feldspars.

Volcanic rocks, lavas, etc., are rocks that have been emitted in a molten state from volcanoes.

Trap is a widely distributed, compact, very dark-colored variety of volcanic rock. Technically it is a basalt or diabase, and these terms are in common use.

Metamorphic and Crystalline Rocks. — Slate is like shale, but harder; it splits into thin plates which may or may not coincide with the bedding. The tendency to split is not often recognized in drilling. Roofing slate is a familiar example.

Marble is a crystalline limestone, and gives the same reaction with acid as limestone, marl and chalk.

True soapstone is a soft, even-grained, greasy-feeling rock composed of the mineral talc, but the term is incorrectly applied to any soft, greasy-feeling rock, such as soft shale.

Schist is a more or less crystalline rock which has a laminated structure, due to the flat crystals of mica or other minerals of which it is composed.

Gneiss is similar to granite in composition, but has a less perfect crystalline structure and a banded structure due to the linear arrangement of its crystals.

Fossils. — In many sedimentary rocks remains of animals and plants are found. These generally consist of portions or impressions of shells, bones or leaves, and are known as fossils. A bed may be recognized and determined by such remains, which are therefore of great importance in geologic work. In the oldest rocks only low organisms, such as shellfish, are found, but in later rocks, fishes, reptiles and mammals progressively appear, while vegetation shows a corresponding change of its predominant types from microscopic forms to the forest trees of to-day.

Formations. — A rock bed or a succession of beds that are uniform in character throughout a considerable area is termed a formation and is given a geographic name derived from some place or feature in the area where it typically occurs, such as Trenton limestone. The correct identification of formations is very important in underground-water studies, as by this means the structure and position of water-bearing beds is worked out.

Structures of Rocks. — When deposited, sedimentary beds are nearly horizontal, but they may be subsequently thrown into inclined positions, or bent into arches or troughs, or broken and displaced. It is rather unusual, in fact, to find in the interior of the continents any sedimentary beds which have not been tilted, folded or otherwise disturbed, at least slightly. Some of the terms used to designate the structures that result from these disturbances are as follows:

An anticline is the arched part of a rock fold.

A syncline is the trough of a rock fold.

A fault is a rock fracture the sides of which have been displaced from their original position with reference to one another.

The dip of a bed is the angle by which it deviates from the horizontal plane.

Strike is the compass direction of the intersection of an inclined bed with a horizontal surface.

A joint is a plane of fracture or crack in a rock the sides of which have not been materially displaced with reference to one another.

Cleavage planes are minor planes traversing a rock, as a rule in one direction, and in many rocks are simply lines along which the rock tends to split rather than actual fractures. They are commonly due to the action of pressure on compact rocks.

Foliation and schistosity are planes of easy splitting, due to the arrangement of the minerals of the rock with their elongated directions parallel with one another.

CHAPTER VI.

SOURCES AND SAFETY OF UNDERGROUND SUPPLIES.

THE water in rocks — and every rock contains at least a trace — either occupies perceptible cavities in the rock or occurs within the minute pores. The water in the pores is given up readily only by the coarser rocks, such as sandstones, the fine-grained rocks yielding very little of such water when penetrated by the drill. Water found in these rocks usually comes from the joint, fault or foliation planes. The conditions of the occurrence of water in various rocks differ widely.

Waters of Sands and Gravels. — Sands and gravels are very porous. Thirty per cent of the volume of some sand or gravel deposits are made up of free space between the grains. In such material the whole mass below ground-water level is saturated, and when penetrated by wells yields copious supplies. The waters of such deposits are, as a rule, of good quality, but some are mineralized, having dissolved material from the more soluble fragments and particles that constitute the deposits.

The cheapest and best method of obtaining small supplies of water from sands and fine gravels is by driven wells, which can be sunk quickly and at slight cost. It is difficult, however, to exclude very fine sand or quicksand from pipes, quicksand frequently penetrating the well and clogging the pipe or ruining the pump. Because of the readiness with which sands and gravels yield their water, wells sunk close together in such deposits may affect one another, the well that draws from the sand at the lowest level taking the water from the higher wells. The readiness of movement of the water also causes important fluctuations of the water in the ground, the level often rising and falling rapidly with the beginning and cessation of rain. To obtain permanent supplies, wells

should penetrate to a level below that of the ground-water surface in the driest seasons. (See Fig. 16.)

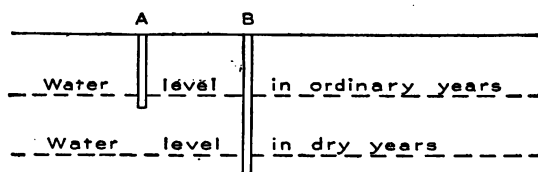


FIG. 16. — Diagram showing relation between depth and permanence of wells. — A, Well sunk to ordinary water level, but failing at times of drought; B, well sunk to level of water in dry years and never failing.

Waters of Clays. — Clay usually contains large quantities of water, but its pore spaces are so fine or small that water soaks into it or out of it so slowly that it is impervious in the sense that little or none of that which it contains can be utilized as a source of supply. Considerable amounts are frequently reported in clays, but they usually come from more or less sandy layers. In some places sand that approaches clay in fineness and that is sometimes mistaken for clay yields considerable amounts of water.



FIG. 17. — Diagram showing action of clays or shales in confining water in sand or sandstone.

Clay is of the greatest importance, however, not as a water bearer, but as a confining layer which prevents the water from escaping (see Fig. 17), or as a layer collecting the water from overlying porous beds and bringing it to the surface.

When, because of the absence of other sources, it is necessary to obtain supplies from clay, a well sunk should be of as large diameter as possible and should be continued far enough beneath the point at which water is obtained to insure ample storage capacity. (See Fig. 18.) Dug wells are usually most satisfactory where the clay is near the surface, but such wells should be carefully covered and guarded from all sources of pollution

Waters of Tills. — Till is a heterogeneous mixture of clay,

sand, gravel and boulders, deposited by glaciers. In texture it varies from porous to impervious, according to whether sand or clay predominates. It is, as a rule, not definitely bedded. The water that it contains generally occurs in small more or less tubular channels a few inches in diameter, but here and there is distributed through interstratified sandy beds.

In the aggregate, till yields a large amount of water, being the prevailing source of supply in the rural districts at a great number of points throughout the northern portion of the country. Be-

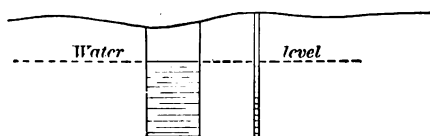


FIG. 18. — Relative size and storage capacity of dug and drilled wells.

cause of the occurrence of the water in definite channels, however, the success of wells in till varies greatly. In general, wells of large diameter give the best success. Figure 18 represents two wells of the same depth, one dug and one bored. It will be seen that in the dug well not only is a larger amount of material encountered in cross section, but the area of surface from which water can enter is many times greater than in the bored well. The open well is also of larger storage capacity, and can be employed to utilize small supplies — supplies that would be insufficient to furnish enough water to a bored well.

Waters of Sandstones, Conglomerates and Quartzites. — Sandstone is, on the whole, the best water bearer of the solid rocks. Under the most favorable conditions sandstone is saturated throughout its extent below the regular ground-water level, and wherever it is struck by the drill within these limits (see Fig. 19) it yields water freely, as a rule, although some of the finer-grained sandstones yield it less readily. In quality the water in sandstones is, as a rule, better than that in any other material except sand and gravel. Drilled wells are used to recover water from sandstone, except where it is very near the surface.

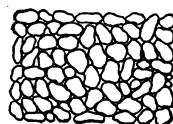


FIG. 19. — Arrangement of grains in sands and sandstones with intervening pores open and capable of holding water.

Some conglomerates furnish considerable water, although, as a rule, the absorptive power of conglomerates is not so great as that of sandstones, and they are much less frequently encountered.

Quartzite is a sandstone in which the spaces between the grains have been filled by hard siliceous matter. (See Fig. 20.) Because of the filling of the pores by this material there is relatively little chance for the water to enter, and the rocks are not commonly an important source of supply. Such water as they yield is mainly from joints.

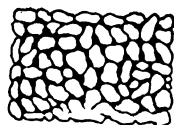


FIG. 20. — Grains in sands and sandstones with intervening pores filled with mineral matter preventing the absorption of water.

Waters of Slates. — Slate, like clay, is a poor water bearer but may yield water from crevices or along bedding joint and cleavage planes. Its most important use, with reference to water supply, is as a confining layer to prevent the escape of water from porous sandstones which may be interbedded with it. The waters in slate are reached by deep wells and are generally uncontaminated but are not uncommonly mineralized.

Waters of Limestones. — Waters occur in limestone mainly in open channels, caverns, etc., dissolved in the rock by the water itself. The water originally probably followed joint or bedding planes which were gradually enlarged by solution into the caverns that now exist.

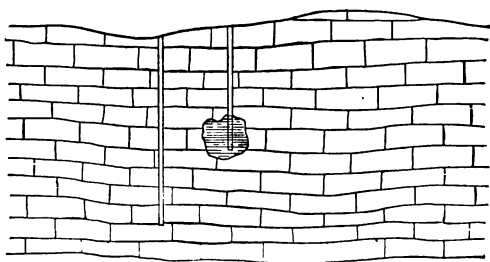


FIG. 21. — Difference in conditions of adjacent wells in limestone.

The occurrence of caverns and passages within the limestone is very irregular, and their location can seldom be predicted. Most deep wells which are drilled in limestone regions, however, encounter one or more such passages at a relatively slight distance below the surface. Wells in limestone, even where only a few feet apart, may never-

theless obtain very different results, as a difference of a foot or two may mean the missing of a certain channel, as indicated in Fig. 21. The waters in limestone are generally hard but are not commonly otherwise mineralized.

Waters of Granites, Gneisses and Schists. — Granites and gneisses are very dense and possess very small pore spaces, and most of these rocks hold very little water. In schists, however, considerable water often penetrates along the foliation planes and

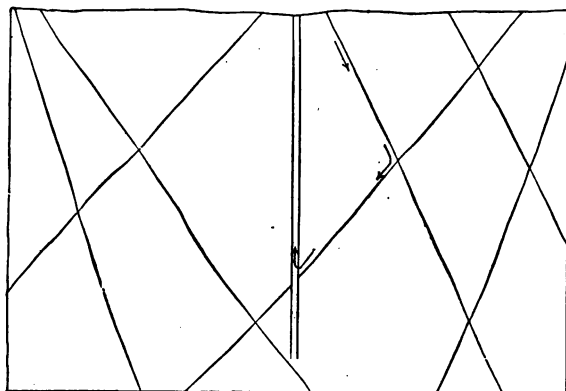


FIG. 22. — Wells in jointed rocks.

is held by the rock, but such water is given up very slowly and is not important as a source of supply.

It is along the joints in these rocks that the largest supplies are obtained. (See Fig. 22.) These joints are most common near the surface and diminish in number

and in definiteness as the depth increases. For this reason the water supplies from such rocks, if obtained at all, are usually found within 200 or 300 feet of the surface. It is generally useless to go deeper than 500 feet for waters in these crystalline rocks, although in some places, as at Atlanta, Ga., water is said to have been obtained at depths as great as 1600 feet.

Safety of Rock Waters. — The safety of the water supplies used for drinking purposes when near any source of pollution, depends principally upon the character of the openings through which the water passes, and this in turn depends on the nature of the materials in which the water occurs or through which it has passed.

In passing downward through sand surface waters are subjected to natural filtration, especially in the finer varieties, and

the substances with which they may have originally been polluted are frequently removed, at least in part. In coarser sands and in gravel the water passes downward more rapidly, the conditions are less favorable for filtration, and the water may remain polluted. In general, however, waters from sands and gravels, if taken from a considerable distance below the surface, are safe to use.

The waters of clays, because of the fineness of the material, come into contact with relatively large amounts of mineral matter and frequently become mineralized, lime and salt being the most common substances dissolved; as a rule, however, owing to the filtration of the waters through the exceedingly fine material and the slowness with which polluting matter progresses and the slight distance to which it reaches in such material, they are free from contamination.

The water of till is generally uncontaminated because of the natural filtration due to its slow downward penetration through

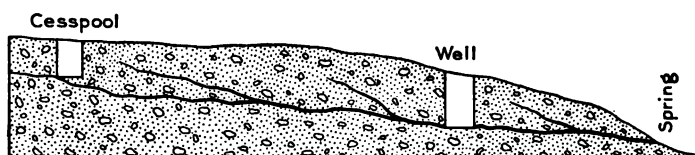


FIG. 23. — Diagram showing pollution in till.

the clay and sand of which the till is largely composed. In some places, however, springs have formed more or less definite tubular channels through the material, and if such a channel leads from a cesspool or similar source of pollution the water becomes highly charged with matter dangerous to the health. Once contaminated it is likely to continue so for long distances, as little natural filtration takes place, because of the nature of the channel. (See Fig. 23.) The water from till should be thoroughly tested by a bacteriologist if there seems any likelihood of contamination.

The waters in sandstones and conglomerates are very rarely polluted, owing in the more porous varieties to the natural filtration and in the compact varieties to the difficulty with which

contaminated waters penetrate them. In quartzitic rock, however, joint fractures may admit both water and polluting materials from the surface.

Like the waters of clays and for the same reasons, the waters of slates and shales suffer very little pollution.

In the vicinity of buildings or settlements the waters of limestone are frequently contaminated and unfit for use. This is not because of the amount of lime dissolved, but because of the fact that the water falling on the surface as rain often plunges directly through basins or sinks into the underground channels instead of slowly filtering downward through the soil and into the rock, as in most other materials. This water carries with it the impurities washed or otherwise brought to the sink and bears them along through underground passages to distant points. (See Figs. 8 and 24.) It is a common practice to dump manure, sewage and

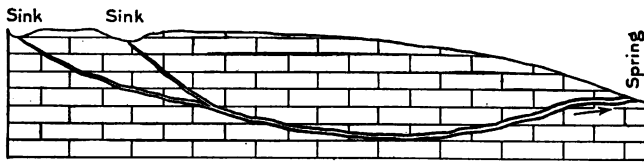


FIG. 24. — Limestone passage connected with sinks.

other refuse into these sinks, regardless of the fact that it will eventually enter the underground water body. Fortunately, in the United States many limestone regions are thinly inhabited, so the danger is not perhaps so widespread here as elsewhere. When springs which have been guarded from surface wash become muddy after a rain it is safe to assume that surface impurities have had access to the ground water through sinks or otherwise, and such waters should be avoided.

The joints in granitic rocks generally occur in complex systems of intersecting planes, and it is possible for polluted water starting very near the mouth of the well to pass in a zigzag course downward along the joints, finally reaching the well at a depth of many hundred feet (Fig. 22); such was the case in a well at

Atlanta, Ga., which finally had to be abandoned. For this reason wells drilled in broken and jointed igneous rocks in cities and other thickly populated regions are liable to pollution. Waters from such wells, if they are to be used for drinking, should be tested occasionally to determine whether they are polluted or not.

CHAPTER VII.

LOCATION AND MOVEMENTS OF UNDERGROUND WATERS.

Fallacy of the Divining Rod.—Numerous mechanical devices have been proposed for detecting the presence of underground water, ranging in complexity from the simple forked branch of witch-hazel, peach or other wood, to more or less elaborate mechanical or electric contrivances. Many of the operators of these devices, especially those who use the home-cut forked branch, are entirely honest in the belief that the working of the rod is influenced by agencies—usually regarded as electric currents following underground streams of water—that are entirely independent of their own bodies, and many uneducated people have implicit faith in their ability to locate underground water in this way.

Rods of this type have been carefully tested by the writer, who early found that at times they worked entirely independently of his will. This, by most people would be regarded as conclusive evidence of their efficacy, and if water was not found beneath the spot where the rod turned down it would always be because one “didn’t go deep enough.”

As a matter of fact, though the rod turned down in the hands of the writer without any volition on his part, careful and continued experiment showed the action to be entirely unrelated to the presence or absence of water, but due rather to slight and, until watched for, unsuspected muscular movements such as leaning forward in ascending a grade or other natural changes of the position of the body resulting from unconscious adjustments of poise to suit the irregularities of the surface on which he was walking, or to other causes, the effects of which were communicated through the arms, wrists and hands to the rod. A slight

and often unconscious tightening of grip on the rod always sent the tip downward at once, and the tighter one held the more it bent.

It was soon shown, however, that there were no movements of the rod arising from causes outside of the body and it was obvious that the view held by other men of science is correct — that the operation of the “divining rod” is generally due to unconscious movements of the body or of the muscles of the hand. The experiments made show that these movements, being largely of a nervous nature, happen most frequently at places where the operator’s experience has led him to believe that water may be found.

The uselessness of the divining rod is indicated by the fact that it may be worked at will by the operator, that he fails to detect strong water currents in channels that afford no surface indications of water, that his locations in limestone regions where water flows in well-defined channels under conditions that should be especially favorable to the working of the rod are usually no better than mere guesses, and that two “divining rod experts” going over the same tract commonly locate the supposed underground “streams” at entirely different points.

In fact, the operators of the divining rod are successful only in regions in which ground water occurs in a definite sheet in porous material or in more or less clayey deposits, such as pebbly clay or till. In such regions few failures can occur, for wells can get water almost anywhere. Ground water occurs under certain definite conditions, and just as surface streams may be expected wherever there is a valley, so ground water may be found where certain rocks and conditions exist. No appliance, either mechanical or electrical, has yet been devised that will detect water in places where plain common sense will not show its presence just as well. The only advantage of employing a “water witch,” as the operator of the divining rod is sometimes called, is that crudely skilled services are thus occasionally obtained, since the men so employed, if endowed with any natural shrewdness,

become through their experience in locating wells better observers of the occurrence and movements of ground water than the average person.

It is to be noted that notwithstanding the pretensions of divining-rod men, especially the inventors of the more complicated appliances, they have not been able to prove their claims to the satisfaction of the government, and all applications for patents are denied by the Patent Office.

Basis of Scientific Location of Underground Waters. — The only scientific basis at present known for locating underground supplies is a knowledge of the laws of occurrence and movements of the ground-water body, for on these factors depend the quantity, quality and safety of the supply. The occurrence and quality of the water in rocks of different kinds has been already discussed in Chapter VI. It remains to consider briefly the nature of the movements of the ground-water body.

The Water-table. — Proceeding downward from the surface in porous or semi-porous materials, such as those in which most open wells are located, a level is soon reached below which the ground is saturated with water (at least down to the first impervious stratum). This water-body, or ground water as it is called, has a definite upper surface, known as the water-table. This is not, like its surface counterpart, a level surface, but slopes gently in various directions, conforming with the broader surface irregularities.

While the water-table is typically developed only in the porous soils and rocks, it commonly exists, even in the dense rocks like granite, as a more or less definite, though irregular, surface, since the joints and other planes which subdivide the rock usually communicate with one another so that the water level stands at a fairly uniform height.

The surface of the water-table, though conforming in a general way with the surface contour, is almost always comparatively flat, its slope being only a fraction of that of the overlying surface. This is brought out by Figure 25, which shows the water-table

lying far below the ground beneath hilltops while cutting the surface in the valleys, giving rise to a line of springs at about the level of the surface streams.

The water-table is flattest in porous materials such as sands and gravels and presents the steepest slopes in clays, often fol-

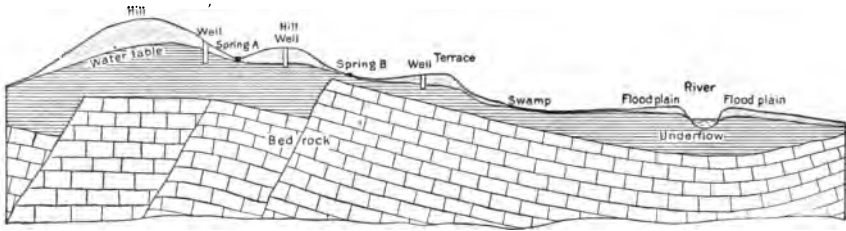


FIG. 25. — Section showing relation of water-table to surface irregularities (Slichter.)

lowing, in the latter type of materials, the surface contour with but slight variation.

It follows from the above that in seeking to locate water the topography and geology should be carefully considered. Supplies are to be expected at shallower depths beneath depressions than beneath the higher lands, and in general will be found nearer the surface in clays and similar materials than in sands or gravels. The waters of the clays, however, are likely to be insufficient for permanent supplies.

Movements of Ground Waters. — The motion of the ground water is in the direction of steepest slope of the water-table, as illustrated in Figure 26, and as this roughly coincides with the surface slope it follows that the direction of motion of the ground water generally approximates that of the surface drainage.

From the law of movement thus outlined it appears that in porous materials the points most favorable for obtaining water are where the water movements converge. This is in the valleys or other depressions, where the water, as shown in the preceding section, is also nearest the surface.

Movements of Shallow Rock Waters. — The movements of rock waters, since the movement is largely controlled by the



FIG. 26. — Map showing position of water-table by contours (continuous lines), lines of motion of ground water (arrows) and surface streams. (Slichter.)

nature of the water-bearing passages, are far more irregular than those in porous materials, in which motion is possible in any direction. In granites, the water is found mainly in joints and can move only in the direction in which the joint planes extend. In shales, it is the cleavage planes that furnish the chief passages for water, and, as these all extend in one direction, the water can commonly move only in one way. In sandstones, water may move in any direction that the bed extends. In limestones, solution channels carry practically the whole of the available water, and, notwithstanding their great irregularity, they commonly have fairly definite trends—from the highlands towards the valleys.

Although the specific direction of movement of the rock waters is controlled by the structural features of the rocks the general movement of the shallower supplies, or those lying above the level of the drainage in the valleys, is very similar to that of the ordinary ground water, the flow trending towards the adjacent valleys in almost every case. It is at such points that supplies will be most easily reached by wells.

Movements and Depth of Deep Seated Waters. — The deep seated waters, or those reached by the deep drilled wells, do not follow the simple laws governing the movements of the ground waters: Although moving from higher to lower points and in the general direction of the broader surface slopes, they are usually independent of local topography and of irregularities in the immediately overlying water-table. They are commonly confined under pressure in channels, joints or other passages in the denser rocks, or in porous beds between impervious strata, and have often been transmitted through the rock from distant sources.

The depth at which the water will be encountered depends upon the slope or dip of the bed or passage in which it occurs. Other things being equal, the depth will be least beneath the valleys and greatest beneath the uplands. If the slope of the confining bed is uniform, the depth will decrease in the direction of the outcrop, providing the surface does not rise more rapidly than the water-bearing bed.

CHAPTER VIII.

ARTESIAN FLOWS.

Requisites of Artesian Flows. — A flowing well may be obtained at any point where water is confined in the earth under sufficient pressure to lift it to the surface, whether this be in drift, in sandstone, in limestone or in granite, or whether the water occupies the pores of the rocks or occurs in bedding planes, joints, cleavage partings or in open solution passages.

The first essential is a reservoir, which, in the scientific sense, is any opening or series of openings in soils or rocks capable of

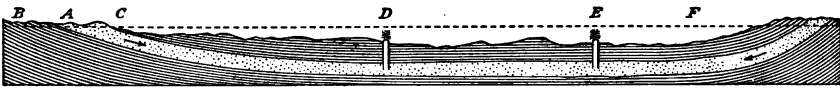


FIG. 27. — Section of an artesian basin. *A*, porous stratum; *B*, *C*, impervious beds below and above *A*, acting as confining strata; *F*, height of water level in porous bed *A*, or, in other words, height in reservoir or fountain head; *D*, *E*, flowing wells springing from the porous water-filled bed *A*. (Chamberlin.)

holding water. This must be filled with water, the escape of which — the second essential — is prevented by an overlying impervious bed or in some one of a dozen different ways. The third essential is an adequate source of pressure. Usually this pressure



FIG. 28. — Section showing transition from porous to impervious bed. *A*, an open porous bed inclosed between impervious beds *B* and *C* and grading into dense non-water-bearing bed at *E*; *F*, original head; *D*, flowing well. (Chamberlin.)

results from the fact that the catchment area of the water-bearing reservoir is higher than the point at which it is tapped by the well.

Three of the simplest and most common artesian systems are illustrated by Figures 17 (p. 41), 27 and 28.

Flowing water is not confined to wells penetrating definite porous beds such as are shown in the figures. Bedding planes (Fig. 4) in limestones and other rocks, joint planes in crystalline rocks (Fig. 29), solution passages in limestone (Fig. 30), porous (vesicular) layers of traps (Fig. 31), etc., all afford artesian flows under favorable conditions.

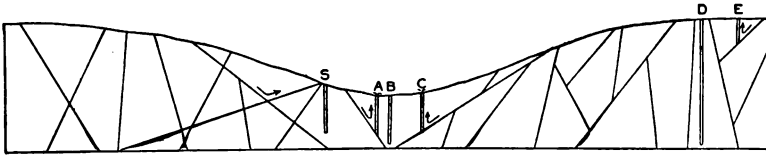


FIG. 29. — Section illustrating artesian conditions in jointed crystalline rocks without surface covering. A, C, flowing wells fed by joints; B, intermediate well between A and C of greater depth, but with no water; D, deep well not encountering joints; E, pump well adjacent to D, obtaining water at shallow depths; S, dry hole adjacent to a spring, showing why wells near springs may fail to obtain water.

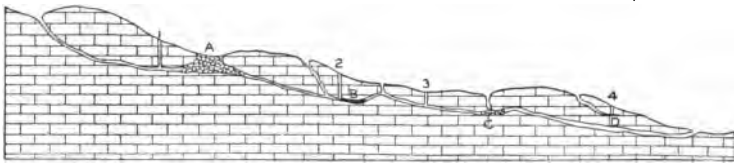


FIG. 30. — Section illustrating conditions of flow from solution passages in limestone. A, Brecciated zone (due to caving of roof) serving as confining agent to waters reached by well 1; B, silt deposit filling passage and acting as confining agent to waters reached by well 2; C, surface debris clogging channel and confining waters reached by well 3; D, pinching out of solution crevice resulting in confinement of waters reached by well 4.

Flows from Sands and Sandstones. — It is the sands and sandstones that give rise to our great artesian systems. Often of great thickness and extending without interruption for hundreds and even thousands of miles, they are frequently saturated with water under sufficient head to lift itself to the surface at scores of points. It is such beds that give rise to the numberless flowing wells along the river valleys, lowlands and shores of the Atlantic Coastal Plain, to the great flows from the Dakota and other sandstones in portions of the High Plains along the east flanks of the Rockies, and to flows in numerous other areas of less extent.

The beds, being continuous, furnish water at practically every point encountered, and since the head is usually known, the obtaining of flows is usually simply a question of elevation of the surface and success or failure may be predicted in advance.

Flows from Glacial Materials. — Consisting largely of sands and gravels, the glacial materials, next to the great sand and sandstone beds, are naturally the most common source of flowing wells. It is rare, however, to find individual beds extending for any great distances, and the areas of flowing wells are, therefore, usually of no great extent. What the areas lack in extent, however, is often largely made up in number, for in regions of thick drift, like Michigan, there are literally hundreds of artesian basins. In fact, throughout much of the Lower Peninsular, almost every valley or other depression of any magnitude yields flows at depths commonly from 50 to 150 feet. Though not so numerous in other parts of the country, local artesian basins abound in the drift at many points. Unlike the case of the sandstones, in which the head of the water depends on the elevation of distant outcrops, the head of the waters of the drift usually depends on the altitude of closely adjacent elevations, often within a mile or two of the artesian basin, and, since the differences of altitude are usually relatively slight, the pressures of the drift waters are not usually high.

Flows from Limestones. — Limestones do not, as a rule, afford many flowing wells. When near the surface, the water, because of the solubility of the rock, generally finds easy escape, seldom remaining confined under pressure. When below drainage level, however, especially where the limestone lies between shales or other impervious beds, artesian flows are not uncommon. The flows in the vicinity of Cincinnati, on the Peninsula of Florida and in portions of Texas are good examples of artesian waters of this type. The volumes are often large.

Flows from Granites. — Granites, gneisses and other similar crystalline rocks, although seldom regarded as a source of artesian waters, nevertheless yield flowing wells at many points where the

escape of the water, which has passed downward through the joints from some elevated source, is prevented from escaping by overlying clays or other obstructions to circulation. Several such wells are found at Portsmouth, N.H., and at other points in the granite areas of New England and the Piedmont plateau of the South, and are occasionally found in the crystalline areas of the West.

The flows from granite are generally small, for the reason that the openings along the joint planes in rocks of this type are very small, being usually under $\frac{1}{100}$ of an inch in width, although when several such passages are intersected by a single well the volume is occasionally higher, amounting sometimes to from 20 to 50 gallons a minute.

Flows from Traps and Lavas. — Certain traps, like those of the Connecticut valley, are often quite porous in their upper por-

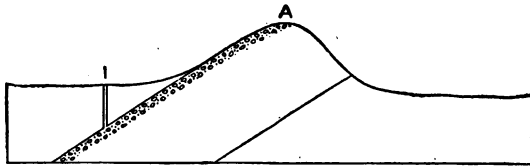


FIG. 31. — Section illustrating conditions of flow from vesicular trap. A, Vesicular zone feeding well I.

tions, and, when overlain by impervious retaining beds, not infrequently give rise to flowing wells. In the thicker lavas, such as those covering large portions of eastern Washington and Oregon, certain strata are sometimes almost as porous as sandstones and afford large volumes of water to wells, many of which flow.

Location of Flowing Wells. — In order that water may have sufficient head to flow out upon the surface, it must be confined under some impervious or relatively impervious clay or other bed. This effectually shuts out pollution from the overlying material, and any contamination that reaches the well must be transmitted laterally for relatively long distances. As pollution rarely extends through the ground to any great lateral distance from its source, it follows that artesian waters are almost never polluted.

In artesian wells, the water, being under greater head than that

in the surrounding materials, will pass outward through any leak that may develop rather than admit the water of lower head to the well. Suction, such as is developed in the Richards apparatus in laboratories, which might be conceived of as drawing in outside water through openings in the casings, can not take place with the relatively low velocities of the water in the ordinary artesian wells. Even in a well in which the water has a very high velocity, the suction is so slight in proportion to the immense volume discharged that it may usually be neglected.

Because of the fact that there is little likelihood of pollution of a flowing well, the exact situation is, from the sanitary standpoint, of little consequence, and the well may generally be located at the point that is most convenient. Since flows are dependent upon the head of the confined water, the pressure of which is generally very moderate, it follows that the well should be located at the lowest point possible. A difference of altitude of a few feet, or even a few inches, may decide whether or not a flow will be secured.

Relation of Depth to Flows. — There is a general belief that the head of underground waters, and therefore the probability of

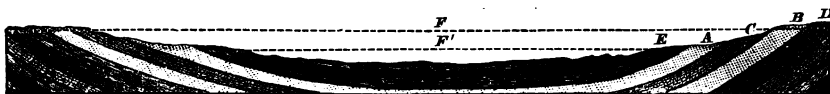


FIG. 32. — Artesian system showing progressively higher outcrop of deeper beds.

securing flows, increases with depth. In many instances, as under the conditions shown in Figure 32, there is some foundation for this assumption, since the deeper beds not infrequently out-

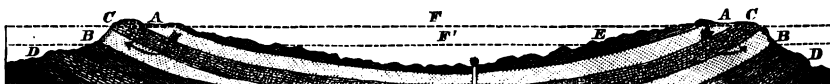


FIG. 33. — Artesian system showing progressively lower outcrop of deeper beds.

crop at successively higher lands than the shallower beds. In other instances the belief is not only without foundation, but the reverse conditions exist, as shown by Figure 33.

CHAPTER IX.

WATER PROVINCES OF THE UNITED STATES.

Principal Water Provinces. — There are wide differences in the underground water conditions in the different parts of the United States. These are due, in a large measure, to the diversified character of the water-bearing materials and to the variations in geologic structure.

An area throughout which the underground water conditions are essentially similar or, more especially, in which the occurrence of ground waters is governed by the presence of some particular water-bearing bed or of some geological structure favorable to the accumulation of ground waters, is known as a ground water province.

There are about a dozen great ground water provinces in the United States; the Drift Province, the Weathered Rock Province, the Atlantic Coast or Coastal Plain Province, the Piedmont Province, the Appalachian Mountain Province, the Mississippi Basin Province, the High Plain Province, the Rocky Mountain Province, the Great Basin Province and the Pacific Province. Several of the major provinces may be subdivided with a number of smaller provinces, and the bounds of one often merge into those of another. Two of them, the Drift and the Weathered Rock provinces, are superficial and overlie the more fundamental, though no more important, provinces based on the underlying geology.

Area of Glacial Drift. — This area is bounded on the south by a line which, starting at Nantucket, passes through Martha's Vineyard, Long Island, across New Jersey, northwestward across Pennsylvania into New York, then southwestward across Pennsylvania and Ohio to the vicinity of Cincinnati, where it crosses the

river for a short distance into Kentucky, thence westward across southern Indiana, Illinois and central Missouri, to a point beyond Kansas City, where it bends northward across Kansas and the Dakotas and thence westward along an irregular line a little south of the international boundary to the Pacific Ocean. All of the region north of this line was covered one or more times by great ice sheets, except a small area in southwestern Wisconsin and adjacent portions of Minnesota, Iowa and Illinois, where there appears to have been a sort of island of land surrounded by ice, known as the "Driftless Area," while local glaciers occurred south of the glacial boundary at many points in the mountains.

North of the boundary mentioned, the surface, except for the small driftless area, is covered with a mantle of materials deposited by the glacier and known as drift. The drift is divided into two main types, the first known as till, and the second as modified or stratified drift. Till is a heterogeneous mass, consisting of clay, sand and boulders, frequently known as hardpan. It was deposited mainly directly by the ice, either beneath the sheet or at its margin. The second class of drift includes gravels, sands and other stratified deposits formed by streams leading outward from the ice sheet. It is found chiefly along the valleys which were once occupied by glacial streams, but considerable amounts were also deposited in temporary glacial lakes which existed between the northward sloping land and the retreating ice sheet, while some was laid down as broad wash plains.

The glaciers which left the various types of drift started in the far north in relatively recent geologic times and spread southward to the limits mentioned. Previous to their advance, the rocks were probably deeply weathered and covered with soil, as in the South at the present time, although the extent of the weathering was doubtless somewhat less. The first work of the ice was to remove this soft weathered material. Part was incorporated with the till and part was carried off by the streams to form clay and sand deposits. Later, after the removal of the

surface soil, the glacier began the work of wearing down the solid rocks, plucking off fragments both large and small from the ledge and transporting them southward. This material was also left in part as till, and in part was carried away by the streams.

The effect of the drift on the water supply of the northern portion of the country is very great. In general, the drift holds very much more water than any of the rocks. This water is yielded readily to shallow wells, and furnishes by far the larger part of the well supplies in the region where it occurs. Water is least abundant in the till and most abundant in the stratified drift. Its occurrence in till and in sand and gravel has already been described (see pp. 40, 42).

Weathered Rocks. — South of the limits of glacial advance the place of the drift is partly taken by the weathered or decomposed rocks. The weathering is deepest in the south where the climate is more humid and, therefore, more favorable to rock decay.

The soils south of the drift limits consist of small fragments or particles of disintegrated rocks. They are usually colored red and yellow by weathering and are very porous, absorbing much water. Their thickness, however, is not sufficient to make them a good source of water supply, although they yield water to many shallow wells. The water is subjected, as in sands and similar materials, to more or less complete filtration in its passage downward.

The Atlantic Coastal Plain. — The Coastal Plain consists of a strip of unconsolidated deposits, extending from Long Island on the north along the Atlantic and Gulf States into Mexico on the south. The width varies from a few miles at the north to several hundred miles in the Mississippi River region.

The surface of the Coastal Plain is low, usually not exceeding 100 to 500 feet above sea level and, where uncut by erosion, is generally flat. Owing to the soft character of the materials, however, the streams have generally cut fairly deep valleys which are separated, where not too close together, by flat-topped ridges marking the original surface. Where the streams are close together the surface is cut into rolling hills.

The materials include clays, sands, gravels, marls and a few more or less solid limestones, the latter being present mainly in the southern states. A few of the sandy layers have been consolidated and now form sandstones. The beds dip gently toward the coast. The waters in the North occur mainly in sands and gravels, especially in those at the base of the Coastal Plain deposits. Farther south, particularly in the Gulf States, water is found both in sands and in the porous limestones. The quality of the water in the gravels in the northern portion of the belt is generally soft and good, but farther south, notably where sands and gravels alternate with clay or limestone beds, the waters are often hard or are charged with sulphur and iron. The capacity of the wells is generally large and many of them flow without pumping. In the aggregate, there are several thousand deep wells scattered throughout the Coastal Plain. They are used principally for domestic and farm supplies, but some of them that yield soft waters are utilized for industrial purposes. In the Gulf States, especially in Louisiana, a large number of wells furnish water for the irrigation of rice. A considerable number are also used as sources of public water supplies.

The Piedmont Plateau. — The Piedmont Plateau proper consists of a belt of crystalline rocks, including a few small basins of Triassic sandstones, that extends southward from southeastern New York along the east front of the Appalachian Mountains to Alabama, lying between the mountains and the Coastal Plain. Where the plateau joins the Coastal Plain its elevation is only a few hundred feet, but the altitude of its surface increases gradually toward the northwest, until at the base of the mountains, especially in western North Carolina and vicinity, its highest points have altitudes of several thousand feet. In the main its surface, where uncut by streams, is flat or gently rolling, but in its higher portions it has been cut into a series of prominent mountains. In the vicinity of the streams near the coast it is also cut into a series of lower hills, as in the case of the Coastal Plain.

The rocks of the Piedmont Plateau proper consist mainly of schists, gneisses, granites and other metamorphic or igneous rocks, all of which are of crystalline texture. The rocks of the Triassic basins consist mainly of sandstones, shales, etc., frequently of a deep red color.

The waters of the Piedmont Plateau are relatively uncertain in occurrence, depending largely on the existence of joints or other fissures in the rocks, but good supplies have nevertheless been obtained at numerous points. In composition the waters are usually fairly good, although they sometimes contain considerable mineral matter. Relatively few deep wells have been sunk in this region, owing to the uncertainty of supply, dependence being placed largely on streams or on shallow wells dug in the weathered upper portion of the rocks. The waters are used largely for domestic and farm purposes and in small industrial establishments. In a few places public water supplies are obtained from the Piedmont rocks, and some important mineral springs are found in the region.

Similar to the Piedmont Plateau are the great areas of igneous rocks in Minnesota and Wisconsin and in New York and New England. The topography of the rocks in these regions is, in general, somewhat more rugged than in the Piedmont Plateau proper, and less use is made of the waters, largely because of the abundance of lakes, springs and spring-fed streams, or of waters in the glacial drift which often overlies the crystalline rocks in this portion of the country.

Appalachian Mountains. — The Appalachian Mountains may be considered as beginning in eastern Pennsylvania and extending southward to central Alabama. The Berkshire Hills in Connecticut and Massachusetts and the Green Mountains in Vermont are included in the area by some. The rocks throughout the region are strongly folded and broken by faults, the harder beds giving rise to the great mountain ridges which characterize the belt. The rocks consist of quartzites, sandstones, shales and limestones. The sandstones and certain of the limestones carry

considerable amounts of water, but are seldom used as a source of supply. The water in the limestones is carried in definite channels and is of rather uncertain occurrence. Both the sandstones and limestones yield copious springs in places. Wells in the synclines or rock troughs frequently yield water which will sometimes rise to the surface, but in general dependence is placed on the springs which occur in large numbers throughout the belt. In the wider limestone valleys wells or cisterns are often used. There are very few cities or large industrial establishments in this region and deep wells are therefore somewhat rare.

The Mississippi-Great Lakes Basin. — This basin includes the remaining portion of the territory in the eastern half of the United States. The surface is moderately low, seldom exceeding 1000 feet in elevation, and is usually not characterized by prominent hills or mountains. Except in the areas of igneous rocks, noted above, the rocks consist of flat or very gently folded sandstones, limestones, shales, etc., varying from Cambrian to Carboniferous in age. The Cambrian and other of the older sandstones carry large amounts of water, which is obtained by wells that frequently flow at the surface. The Silurian limestones also contain considerable water, but, as is the case with water in limestones elsewhere, its occurrence at a particular point can seldom be predicted.

The younger rocks, including the Devonian and Carboniferous, consist to a considerable extent of alternations of shales, shaly limestones and sandstones. In the limestones the water occurs very much as in other limestones. In the sandstones and shales, however, its occurrence is uncertain owing to the lack of persistence of the beds. One well may obtain water, while another a few feet away may fail. The waters are often mineralized, especially in Michigan, where they contain a high percentage of salt. The Carboniferous limestones abound in springs, some of which are of great size.

The High Plains. — Stretching eastward from the flanks of the great Rocky Mountain range and underlying large portions of

North and South Dakota, Nebraska, Kansas, Oklahoma and Texas is the broad belt of Cretaceous and Tertiary beds forming the so-called High Plains.

These beds, which consist of a great thickness of clays, clayey sands and sands with some limestones, dip gently eastward from their catchment areas near the mountains on the west. Their more porous beds, especially the Dakota, Arikaree and other formations, are commonly saturated with water which is freely yielded to wells. In the western portion of the High Plains the great water-bearing formation, the Dakota sandstone, which occurs near the base of the series, is relatively near the surface and yields large supplies to wells, and, in the deeper river valleys, may even give rise to flowing wells. On the higher lands between the streams the water is generally raised to the surface by windmills or by some one of the various forms of power pumps. A cattle-raising industry of large proportions is made possible by the waters thus obtained.

To the east the Dakota waters are at depths beyond the limits of ordinary drilling and higher formations have to be depended upon. Besides the deep waters, the shallow underflow in the gravels of dry or nearly dry stream beds are extensively utilized throughout large portions of the High Plains Province.

In addition to the sands and sandstones of the High Plains, the limestones are also frequently important water bearers, especially in Texas, where they not only afford supplies to many wells, but also give rise to numerous large springs.

The Rocky Mountain Province. — In the Rocky Mountain Province are included the numerous ranges that go to make up the great Rocky Mountain system. Though comprising several geographically distinct provinces, they may, because of the similarity of ground water conditions, be considered as a unit.

As in the Appalachian Mountains, the rocks are greatly disturbed. In general, the character of the rocks and the topographic and geological structure is such as to prevent the existence of water systems of more than local importance or extent. Fortu-

nately, within the mountains, springs are numerous, while the valleys are often filled with gravels that yield satisfactory supplies to wells. The rocks themselves are not generally a satisfactory source of water for wells.

Along the flanks of the Rockies, especially those facing the Great Basin, broad deltas or fans of gravel, washed out by torrential streams from the mountains, are often extensively developed. These are commonly saturated in their lower portions by waters supplied from the hills and frequently furnish abundant supplies when penetrated by wells.

The Great Basin. — By the Great Basin is meant that broad tract of desert or semi-desert land lying between the Rocky Mountains and the Sierra Nevadas. It is by no means an uninterrupted trough, but is broken by numerous mountain ranges, ridges and mesas rising sharply above its general surface, often the result of tilted fault blocks of immense size. The rainfall is slight and the rocks of the elevations are commonly bare and shed the scant rain almost as it falls, giving rise to the torrential rushes of water down the numerous canyons that form so characteristic a feature of the region.

Slight as is the precipitation, however, considerable volumes of water find their way into the broad valley or trough-fillings between the Basin ranges. These unconsolidated sands and silts, partly deposits from the meandering streams of a past geologic epoch and partly accumulations in lakes that have long since disappeared, often contain water within easy reach of the surface and form an important source of supply throughout great areas, especially in Utah, Arizona and southern California. In a number of localities, especially in the California district, the deeper waters are under sufficient head to afford flowing wells. Such waters are important sources of supply for municipal, ranch and irrigation purposes.

The great lava beds of eastern Washington and Oregon and of Idaho fall within the Great Basin Province, and constitute one of the most important water horizons of the West.

The Pacific Provinces. — Under this term are embraced several sub-provinces, including the Sierra-Cascade, the Central Valley, the Coast Range and the Pacific Coastal Plain provinces.

The Sierra-Cascade and Coast Range provinces are not unlike the Rocky Mountain Province. Along the Sierra and Cascade mountains considerable moisture is condensed by the high peaks. The water finds its way down the mountain slopes and into the gravels at the base, from which it passes outward into the deep alluvial deposits of the great Central Valley of California, lying between the Sierra and Cascade ranges on the east and the Coast Range on the west. This valley, which is a province by itself, is an important source of underground water. The conditions along the Coast Range are similar to those of the Sierra-Cascade Range. The Pacific Coastal Plain, though developed only in scattered patches, is marked by deposits of considerable thickness and yields much water in southern California, around Puget Sound and elsewhere.

CHAPTER X.

TYPES OF WELLS.

Types of Wells. — Because of their cheapness, convenience and fancied safety, wells are by far the most popular source of domestic supplies in all regions in which water is found at reasonable depth.

The following tables show clearly and concisely the characteristics and methods of sinking the common types adapted to unconsolidated materials.

Types of shallow wells and conditions to which they are adapted.

Type of well.	Description.	Conditions to which well is best adapted.
Dug.....	Generally circular excavations, 3 to 6 feet in diameter, dug or blasted by hand and curbed with wood or with stones or bricks laid without cement.	Adapted to localities where the water is near the surface, especially where it occurs as small seeps in clayey materials and requires extensive storage space for its conservation. Should not be near sources of pollution.
Bored.....	Bored with various types of augers from 2 inches to 3 feet in diameter, rotated and lifted (together with the earth) by hand or horsepower. Curbed with wood, cement or tile sections, with open or cemented joints, and more rarely with iron tubing.	Adapted to localities where the water is at slight or medium depths and to materials similar to those in which open wells are sunk.
Punched.....	Small holes, usually under 6 inches in diameter, sunk by hand or horsepower, by dropping a steel cylinder slit at the side so as to hold and lift material by its spring. Clay is added to incoherent materials like sand to bind them together so that they can be lifted.	Adapted to clayey materials in which water occurs as seeps within 50 feet of surface, but not at much greater depths.
Driven.....	Small iron tubes, usually 1½ to 4 inches in diameter and provided with point and screen, driven downward by hand or by simple hand or horsepower apparatus.	Adapted to soft and fine materials, especially to sands and similar porous materials carrying considerable water at relatively slight depths. Particularly desirable where upper soil carries polluting matter.
Wells sunk by jet process..	Sunk by forcing water down small iron "jet pipe" inside of casing, the water rising between the two with the drillings. Casing sinks by own weight or is forced down by jacks or otherwise. Diameter usually 2 to 4 inches.	Adapted to soft materials capable of being readily broken up by the water jet, especially to sands, etc., carrying considerable water at relatively slight depths. This method is an improvement over driven wells, which are adapted to same conditions, because it affords samples of materials penetrated. Quick and fairly cheap and especially useful in sinking large numbers of test wells in adjacent localities.

Although no two wells are exactly alike in all particulars, there are, in reality, only a few distinct forms, the others being simply modifications or combinations of these. The kind of well to be sunk at a particular locality depends mainly on the nature of the material to be encountered, one form being particularly adapted to a certain material such as sand, while an entirely different form is demanded if rock is to be penetrated.

For deep waters entirely different types of wells are used. These include: (1) the California or stove-pipe well sunk in thick unconsolidated deposits by forcing down by jacks a sheet-steel casing; (2) the standard drilled well sunk by the drop of a heavy iron bit; (3) rotary process wells sunk by rotating a hollow bit fitted with cutting shoe and (4) various forms of the so-called hydraulic wells in which water is made to assist in the drilling. Such wells are usually from 2 to 12 inches in diameter and require heavy and often elaborate machinery for their sinking. They are often of considerable depth, it not being uncommon to continue drilling to depths of 1000 and sometimes 2000 feet if water is not found at higher levels.

The common deep-well methods and a few of their variations are considered in more detail in Chapter XIV and statements given as to the conditions to which they are adapted.

Types of Curbing and Casings.—Just as there are various types of wells, so are there various methods of curbing and casing (or lining) the well, each method being likewise particularly adapted to a special type of well or to a certain definite kind of material. The common types of curbings and the conditions to which they are best adapted are shown in the following table.

Types of well curbs and casings.

Type.	Nature.	Conditions to which best adapted.
Rock.....	Broken or dressed rock laid without cement, usually in circles 3 to 6 feet in diameter.	Adapted to shallow dug wells, in materials carrying water mainly as small seeps, where there is no near-by source of pollution.
Brick.....	Porous brick laid without cement, usually in circles 3 to 6 feet in diameter.	Same as rock curbs.

Types of well curbs and casings (Continued).

Type.	Nature.	Conditions to which best adapted.
Cement-lined rock or brick.	Brick or stone as above, but laid in and lined with cement.	Adapted to shallow dug wells in materials carrying enough water to permit an adequate supply to enter at the bottom. Can be used in polluted soils if the contamination is superficial and does not reach to the bottom.
Wood.....	Square wooden boxes in wells over 3 feet in diameter; cylindrical curbs of narrow staves in wells under 3 feet in diameter.	Can be placed in any shallow well, but are never safe and should never be used.
Tiles.....	Glazed sewer tile, cement tile and porous terra cotta tile, laid without cement.	Adapted to conditions similar to those of rock and brick curb.
Do.....	Glazed sewer tile and cement tile with cemented joints.	Same as cement-lined stone or brick curbs, except that it is more applicable to wells of small diameter.
Heavy iron casings.....	Iron pipes, 1 to 4 inches in diameter, with tight joints.	Adapted to wells of all depths in which water is obtained from a stratum below the casing, or from strata between cased sections. Not adapted to strongly corrosive waters.
Sheet-iron casings.....	Iron pipes 4 to 16 inches in diameter, with snug joints.	Adapted to wells of all depths, in loose material, in which it is desired to procure water from a number of strata.

In some types of wells — for example, in dug, bored and punched wells — several kinds of curbing or casing may be used, and the selection should be governed by the sanitary protection or resistance to the entrance of pollution which the casing affords. The advantages and disadvantages of the common forms of curbs and casings are indicated in the tabulated statement below.

Summary of advantages and disadvantages of different types of well curbs and casings.

Type of curbing.	Advantages.	Disadvantages.
Rock.....	Allows all water to enter, thus utilizing all seeps. Material often costs little or nothing. As a rule requires little money outlay for labor.	Polluting matter enters readily and well is never safe if near sources of contamination. Affords no filtration and permits dirt and soil to enter. Permits entrance of mice and other small animals at top.
Brick.....	Where uncemented it allows all water to enter, utilizing all seeps. Filters out most of sediment. Does not allow small animals to enter. Involves little money outlay for labor.	Polluting matter enters readily and well is never safe when near sources of contamination. Material costs considerable.
Cement-lined rock or brick.	Safe from pollution (except that entering at bottom) as long as walls are not cracked. Prevents entrance of sediments. Prevents entrance of animals. Does not impart taste to water.	Utilizes water from bottom only. Is unsafe if so shallow that polluting matter can reach its bottom. Costs considerably more than uncemented wells. May require skilled labor.
Wood.....	Cheap in many localities. Can be used in wells of very small diameter. Does not taste of iron.	Swells tight in wet ground, the water either entering at bottom or (after sudden rises) through shrunk portion at top.

Summary of advantages and disadvantages of different types of well curbs and casings (Continued).

Type of curbing.	Advantages.	Disadvantages.
Wood (continued)		Pollution enters readily. Animals gnaw through. Wood rots, giving taste to water and favoring development of bacteria. Expensive in some localities.
Glazed and cement tile with uncemented joints.	Allows all water to enter, utilizing all seeps. Does not give taste to water. Does not require skilled labor.	Polluting matter enters readily and well is never safe if near source of contamination. Soil may wash in through joints. Requires some outlay for material.
Glazed and cement tile with cemented joints.	Safe from pollution (except that entering at bottom) as long as joints are tight. Does not require expensive labor.	Can be used only in soft materials containing considerable water.
Iron casings	Adapted both to rock and to unconsolidated materials. Safe from pollution except that entering at bottom.	The cost in large deep wells is considerable. Practically limited to wells under 14 inches in diameter. Is subject to deterioration by corrosion and incrustation in some places. Utilizes but one water stratum (except where perforated).

Selection of Type of Well. — The type of well is the first and perhaps the most important point to be decided. Of the many kinds in use, including the dug, bored and driven types and wells sunk by the jet process or drilled by rotary or percussion rigs, each possesses, on the one hand, one or more points especially qualifying it for use under one or more of the many varying conditions encountered in drilling, and, on the other hand, some disadvantage which may disqualify it for use under certain other conditions. The chief factors which govern the selection of type are, usually, the amount of water needed, the character of the materials to be penetrated, the depth to which the well must be sunk, the cost of sinking the well and the safety of the resulting supply. These factors are considered in detail in the following paragraphs.

Yield as a Factor in Determining Type of Well. — If an adequate supply of ground water is available, the yield of a well will depend on the character of the water-bearing material, the facility of entrance of water, the size or storage capacity of the well and the nature of the pumps.

The character of the water-bearing material is of the greatest importance in determining the yield of a well, as it is on the

structure and texture of the water-bearing beds that the amount of water which they will give up depends. A close-textured clay, for instance, may hold as high as 50 per cent, while an open-textured sand may hold as little as 25 per cent of its volume. Notwithstanding this, a sand will ordinarily yield large supplies, whereas a clay will yield little or no water. In quicksands water is usually present in large amounts, but owing to the absence of good foundations for the curbing and the ready flow of the fine sand through the minutest crevices, ordinary dug wells in such material are generally out of the question and even driven wells equipped with the ordinary strainers usually soon become clogged. Driven or drilled wells equipped with special screens and sunk by experts familiar with the various methods of handling quicksand are usually the only types entirely successful in such material.

Structures, such as solution passages, bedding planes or joints, play an important part in determining the yield of a well. A solution passage in limestone may afford inexhaustible supplies where the mass of the rock is practically destitute of water. In other rocks the bedding planes and joints may afford excellent supplies where no water is found in the rock itself. The amount of water present in the pores of different rocks is indicated by the following average porosities: Sandstones 10 per cent, shales 4 per cent, limestones 5 per cent, crystalline rocks 1 per cent. The water present in the larger openings mentioned, though small in amount in comparison to that held in the pores, is yielded much more rapidly and, except in sandstones and similar porous rocks, usually affords the principal source of supply.

The facility with which water enters the well depends in part on the rock features enumerated and in part on the nature of the well. In loose materials water accumulates most easily in stone-curbed and similar types of dug wells and slightly less so in tightly curbed dug wells with open bottoms. Where the water bed is a strong one and the materials are sufficiently consolidated to prevent them from entering the well the water will freely enter an

iron casing open at the bottom. In weak water beds, in soft materials and in quicksands, either perforated casings or casings equipped with long screens are necessary to permit the entrance of the required amount of water. In many of the harder rocks the walls will stand without caving and casings are therefore unnecessary, the water entering at any point without hindrance.

Where strong water beds exist storage is unnecessary, the water entering from the rock as fast as the pumps demand. Where the supply is derived from weaker beds, especially those having only small seeps, storage is an essential factor and the type and size of the well are of great importance. The volume of tubular wells of equal depth varies with the square of their diameters; hence, a 6-inch well will hold nine times as much water as a 2-inch well of the same depth, and a 3-foot well thirty-six times as much as a 6-inch well. Dug wells are therefore of advantage in clays and similar materials where the water enters more slowly than it can be lifted by the pumps, for they permit accumulations that may tide over periods in which the amount used is greater than the supply. For the deeper rock waters dug wells are impracticable and small-bore drilled wells must be used even where the supplies are slight. To get the best results the wells are generally made as large as can be afforded and sunk considerably below the point of entrance of the water, to afford the necessary storage.

Relation of Depth of Water to Type of Well. — The depth of the water is a factor of importance in the determination of the type of well to be sunk. A dug well, for instance, is suitable only when the water is within 30 or 40 feet of the surface, although many deeper dug wells exist. A punched well is commonly limited to depths of 50 feet, and a bored well is with difficulty carried to depths greater than 100 feet. Driven wells are most suitable at depths of less than 150 feet, although they are sometimes successfully extended to depths of 250 to 300 feet, or even to 400 or 500 feet or more, where the conditions are favorable. Jet wells are usually sunk only where it is not necessary to go

much more than 100 feet from the surface. Wells of the California type are frequently extended to depths of 1000, and occasionally to depths of 2000, feet. Hydraulic rotary wells are successful to depths of 1000 or 2000 feet in the proper rocks. The percussion or churn drill may be used for all depths down to 5000 feet or deeper if special outfits are provided. Diamond drills have been successfully used to depths of 6000 feet.

The Cost Factor. — So many items, such as accessibility to fuel, cost of labor, trade combinations, knowledge of water conditions, relative availability of different drilling outfits and local practice, enter into the cost of a well that only comparative statements can be made. Instances are not uncommon where wells of certain types have been put down for one-tenth the price demanded for wells of the same type in other regions where conditions are essentially similar. In general, however, if only actual outlay of money is considered, the dug well is the cheapest, for it may be constructed by the owner himself at times when he has nothing else to do. Bored and driven wells do not require expensive rigs and are often cheaper than dug wells when paid labor is employed in their construction. The California type of wells is moderately cheap in soft materials if the proper outfits are available, but unfortunately their use is as yet confined mainly to a single region. The jet process is adapted to the sinking of a large number of adjacent wells in soft materials, especially sand, and is occasionally successful for single wells, although in most places driven wells can be put down at less cost. The hydraulic and rotary processes may be cheaper than percussion drilling where there are numerous alternations of hard and soft material. Of the processes in use for drilling in rock the standard rig (percussion drill) is the cheapest, the calyx and diamond systems being generally used only when cores of the rocks penetrated are desired. Further details of cost are given in Chapter XVI.

Comparative Safety of Types. — The safety of a well depends on the purity of the water at its source and on its protection

against the entrance of contaminated waters and polluting solids. The type of well does not affect the purity of the original source; but if the water supply is primarily pure, its maintenance in that condition depends largely on construction that prevents contamination.

Polluting matter finds entrance to wells in a variety of ways. In dug wells it enters through the crevices in the stone, brick or wood curbing, or possibly through the brick itself; in bored wells it enters through the uncemented joints of the tiling or through cracks between the staves of tubular wooden curbing; and in drilled and driven wells, through leaky joints or holes eaten in the iron casing by corrosive waters. By cementing the interior surfaces of stone or brick curbed wells, by replacing wood by cement or other impervious curbs, and by substituting new pipes for leaky iron casings the entrance of polluting matter through the walls can be prevented. Little or nothing enters the small tubular wells from the top and they may, therefore, be regarded as free from danger of pollution from this point. The larger open wells should be protected by a water-tight iron or cement cover standing somewhat above the level of the surrounding ground and tightly joined to the curb proper. The sloping of the earth away from the well serves to turn rainwater or pump drippings away from it, so that little will penetrate, even if the curb becomes cracked by frost.

A particularly dangerous type of well — the more so because of the fancied security of the owners — is the combination dug and drilled type. Because of a slight saving of expense, drilled wells are frequently sunk in old dug wells, the casing commonly beginning at the bottom of the old well. Although the water encountered by the deep well may be perfectly pure, it is liable to be contaminated, especially after rains, by the entrance of seepage waters into the open well and thence into the drilled well. The remedies are obvious; either the casing should be carried to the surface of the outside ground, or at least above the highest level ever reached by the water, or the open well should be converted into a water-tight cistern by the application of a thick coat of cement over both sides and bottom.

CHAPTER XI.

DUG WELLS.

Advantages and Disadvantages of Dug Wells. — Dug wells, because of the ease with which they may be constructed by the farmer himself when other work is not pressing, require little money outlay and are therefore very popular. As commonly sunk, however, they are the most dangerous of all sources of water, but with certain precautions, discussed below, they may be made to yield satisfactory supplies.

The merits and drawbacks of this class of wells are concisely summarized in the following table:

<i>Dug wells.</i>	
Advantages.	Disadvantages.
Ease of construction; can be located, sunk and cased by owner. Only hand power required. No outfit required. No expensive materials required for curbing. Cheapness in soft material.	Limitation to soft materials; liability to caving while being dug.
Ease of entrance of water.	Costliness in hard rock.
Utilization of all water strata.	Wood curbing often used affords favorable conditions for the development of bacteria.
Utilization of small seeps.	Slight depth to which it can be sunk.
Quick response to rainfall.	Ease of entrance of polluting matter through and over top of curb.
Large storage capacity.	Water, not being replenished, is often stagnant.
Accessibility for cleaning.	Fails frequently in time of drought.
	Must usually be at distance from house and from barns, privies and cesspools to insure safety.
	Necessity for frequent cleaning; danger from gas while cleaning.
	Short life when curbed with wood.
	Ease of entrance of animals and refuse through open top.

Importance of Proper Location of Dug Wells. — Upon the proper location of the dug well, both the quantity and purity of the water supply, in a large measure, depend. The chief considerations in the location of open wells and wells in which pervious casings are used, in the order of importance usually ascribed to them by the owners, are: Cost, accessibility, convenience and

safety. The requirements, unfortunately, often conflict. Most houses and barns are located on elevations for the sake of good drainage, sightliness or other considerations, but wells in such situations are rarely as cheap as the less convenient wells in the hollows. Again, convenience often demands that the well be located near the house, where slops are thrown upon the ground, in the vicinity of a cesspool or privy, or near the barnyard or hogpen, while safety demands its location on high ground at a considerable distance from these and other sources of pollution.

In cases of conflicting requirements it is too often the cost which eventually determines the location, or rather it is the initial cost, for in many instances the final cost of a proper installation — if the cost of the resultant loss of health is considered — is much less than that of an improper installation although the latter may not produce actual disease.

A safe well is nearly always, in the long run, the cheapest, such a well being decidedly cheaper than the cost of medical attendance. Safety should invariably be made the first consideration instead of the last. A well should never be put down in a doubtful situation, even as a temporary makeshift, for the owner almost always waits until too late before replacing it.

The safety of a well depends upon its protection from all forms of pollution, both that which enters from the surface and that seeping through the ground. A consideration of the sources of contamination is, therefore, of paramount importance.

Sources of Pollution. — Open or dug wells may be polluted by material seeping through the ground and curbing or entering from the top of the well. Of the seepage materials cesspools and privies are the most important source. In most localities the large amount of liquid reaching such receptacles is rapidly absorbed by the earth and becomes a part of the water-body feeding the wells. Slops thrown on the surface likewise soak into the ground, and even if the liquid at first evaporates the residue is later taken up by the rain which sinks into the ground, and is carried downward to the ground-water body. The matter leached

from hen yards, from hogpens and from the manure piles near barns, eventually enters the ground and finds its way in one form or another to the ground water below. Drainage from manured fields and from pastures occupied by stock may also be a prominent source of pollution. Much of the polluted water from such sources is purified by passage through the ground and the danger of pollution of well waters by seepage is commonly exaggerated, yet gross carelessness in locations of wells near privies, cesspools, drain-pipes and other filth receptacles is prevalent in many farm districts.

One of the greatest sources of pollution for farm wells is the entrance of material at the top, and dug wells are especially liable to contamination of this sort, though other well types are not entirely exempt (Fig. 34).

Of the material entering a well from the open top dust is an important source of contamination. It is always present in the air and the amount actually settling is very many times more than the conspicuous dust coatings collecting in buildings. In fact, in open wells, especially in regions where brisk winds are common, the accumulations sometimes amount to several inches in a year. Many wells which are cleaned only once in two years are found to contain as much as 6 inches of foul-smelling black muck, representing the dust and other refuse entering the well in that length of time.

Small animals, such as toads, mice, moles and snakes, fall into the well in times of drought when the sources of water they usually depend on have failed.

Except that it keeps the larger animals out and is a convenience in using the well, the ordinary plank covering affords but little improvement over the open well. Crevices almost invariably exist through which the smaller animals may find access, and the dirt washed through the cracks by the pump drippings may be almost equal to that entering through an open top. Moreover, it is a very dangerous type of dirt, as in many places it includes filth from domestic fowls and from the shoes of farm



FIG. 34. — Open dug well and wooden bucket. (Photo by U. S. Geological Survey.)



FIG. 35. — Bored well showing wooden curb and valve bucket. (Photo by U. S. Geological Survey.)

hands and others coming from manured fields, hogpens or barnyards.

The "Safety Distance" Factor in the Location of Dug Wells. — By "safety distance" is meant the distance from a source of pollution at which a well may be sunk with a fair degree of safety. Some writers have spoken of a "cone of safety," by which is meant an inverted conical section of earth with its apex at the bottom of the well and its base a circle of some fixed radius on the surface. The radius taken by some is the depth of the well, by others twice the depth of the well, but such limits are usually fixed without taking into consideration the nature of ground-water movements or the character of the passages in which it moves. The distance of safety also depends to a considerable degree on the quantity and concentration of the pollution entering the ground water. Where coming from the surface the amount is commonly not large, but where entering at a considerable depth, as from cesspools sunk in limestone or in porous sands which also supply water to wells, it may reach the water stratum almost undiluted. It follows that no absolute radius can be laid down, each case demanding individual consideration. Certain generalizations, however, may be made as to conditions in materials of different types and under different topographic conditions, some of which are indicated below.

In ordinary clay and in the pebbly or boulder clay known as "till" the water circulates in part by general seepage through the mass, in part through relatively thin sandy layers and in part along more or less open but irregular tubular passages. Seepage through the body of the clay or till is very slow and polluting matter is rarely carried for any great lateral distance; 100 feet from the nearest source of pollution may perhaps be regarded as a safe limit. The clay offers even more resistance to the passage of water directly downward, a 5-foot bed as a rule effectively shutting off polluting matter from the underlying water beds, unless such matter obtains access along the break made in sinking a well or other excavation. When the water follows sandy layers

the movement, though much faster than in uniform clay, is nevertheless not very rapid, rarely exceeding a few feet per day, and pollution does not often extend much over 150 feet, 200 feet usually being a safe distance. In open passages movement is much more rapid and may amount to several hundred feet a day in extreme cases. Under such conditions there is no purification and relatively little dilution, and if the passage discharges into a well dangerous contamination may result. In a thickly inhabited region a well depending for its supply on passages of this nature is never safe.

A bed of sand is among the safer water beds. Being of an incoherent nature, the material rarely contains open passages, the water circulating in general by a slow movement among the grains. The rate, though sometimes amounting to 50 feet or more a day, is usually under 5 feet and may be under 1 foot. A well 200 feet from the nearest point of pollution is probably safe in fine and medium sands, but in coarse sands and gravel a much greater distance may be essential.

The movement of water in sandstone is in part through the body of the rock and in part through small open passages along the joint or bedding planes. Owing to the greater density of the rock resulting from the cementation of the grains the distance to which pollution may extend through the pores of the rock is less than in sand, 100 feet usually being a safe distance. Probably even with the water moving along the joints and bedding planes 125 to 150 feet from the source of pollution is a safe distance for a well.

In slate and shale the water follows in part the planes of stratification or bedding and in part the more or less vertical joints by which these rocks are usually cut. Unless certain of the layers are sandy the movement along the bedding planes is generally slow and pollution is carried for only short distances. The joints, however, are in many places fairly open and may conduct the water within a short time to considerable distances, possibly many hundred feet, like the granite joints described on p. 44. However, unless the examination of the rock or the behavior of the

drill in the well shows the presence of such open joints, a well in slate or shale may usually be considered safe if not less than 100 feet from a source of pollution.

The movement of water through limestone is almost entirely by means of open passages. Some of these are only a minute fraction of an inch in width, being no wider than joint and bedding planes. In such passages the movement of water is very slow and pollution is rarely carried far, 150 feet from a possible source usually being a safe distance. Other passages, however, are of considerable size, perhaps many feet in diameter, and may extend for miles. One chamber in Mammoth Cave is several miles long, and there is evidence that similar though perhaps smaller channels exist at numerous other points. These openings are not uncommonly occupied by flowing streams which, if polluting matter is introduced, may carry it for many miles. Such streams may have connection with surface sink holes. Cornstalks and other refuse from the surface not infrequently appear in wells drawing water from limestone, and the waters are often muddy after storms. Such occurrences are indications of surface contamination and the waters should be avoided if possible.

Practically no water passes through the body of granite, the movement being mainly along joint or fault planes or through pore spaces in the disintegrated upper portions of weathered granite masses. Polluting matter may reach to considerable distances through joint or fault planes, as is indicated by the fact that the salt water of the ocean finds entrance to some wells located 500 feet, and in places even a quarter of a mile or more from the shore. It is said that in the deep public well sunk in granite at Atlanta, Ga., sufficient polluting matter entered through a joint struck at 1160 feet from the surface to render the water unfit for drinking.

Best Situations for Dug Wells. — The best locations for dug wells are those points at which there can be no possibility of the access of polluting matter. The usual distance to which such matter travels has been discussed in the preceding section.

If a well is to be located at a less distance from source of pollution than that prescribed, it should be dug on higher ground, so that the moving ground waters will carry the impurities away from, rather than toward it. It is far better to spend the few additional dollars required (because of the greater depth to the water) to sink a well on higher ground than to risk sickness by locating it where there is danger of pollution. It is not sufficient that the mouth of the well be above the source of pollution. The water level in the well must also be above the source of contamination, even when farthest depressed by drought or pumping, for otherwise pollution-bearing seepage might soon find its way to the well.

Digging the Well. — The process of constructing the common dug well is so simple and so familiar that a few brief statements will suffice.

By far the greater number of dug wells will naturally be of circular cross section, since, for a given capacity of water, less material will be required for curbing. Moreover, the curbing, if of stone or brick, is more easily laid and is less liable to cave under the pressure of the surrounding earth.

The original excavations commonly vary from 6 to 10 feet in diameter where stone is to be used for curbing. Such curbings, even in the smaller and shallower wells, are seldom under 15 inches in thickness and in the larger and deeper wells often have a thickness of from 2 to 2½ feet. The finished wells, where the excavation is 6 to 10 feet, will, therefore, seldom be more than from 3 to 6 feet in diameter. When bricks are used for lining the well the thickness of the walls is usually much less, being seldom more than half that of the stone curbs. The same is true of the cement curbs, which are occasionally used for that portion of the well lying above the water level. A thickness of 12 to 15 inches is usually sufficient for depths down to 15 or 20 feet, but somewhat greater thicknesses are required for the deeper wells. The cement is laid between inner and outer forms, or, where the earth is stiff enough to stand alone, between an inner form and the outer wall of the excavation.

The excavation for dug wells that are to be curbed with wood are generally square and of slight depth. The joints on which the boards are nailed are preferably placed on the outside next the earth walls. Such curbings, however, are undesirable in almost every particular and are to be avoided wherever possible.

In digging open wells there is always grave danger of caving, although such wells are not unfrequently carried (in stiff clayey materials) to depths of 40 to 60 feet or even more without the use of any support whatever for the walls. In sandy and other incoherent materials, however, temporary supports are generally necessary to protect the workmen if the well is carried to any depth.

Size and Depth of Wells.— Ordinary clay and the denser varieties of pebbly and boulder clay or till usually contain but little water, and this little is often largely in the form of interstitial water held in the body of the material and given up slowly to a well by general seepage. Under such conditions the amount entering the well is often more or less proportional to the area of surface exposed in the wall. This area varies with the diameter of the well; thus, three times as much surface will be exposed in a given height of wall in a 6-inch well as in a 2-inch well and six times as much in a 3-foot as in a 6-inch well. To give a large yield a large-diameter well is very desirable in materials of the character mentioned.

Large wells are also desirable in rocks in which the water occurs in a similar manner, that is, in pores rather than in open passages. In general, however, if water is yielded at all by the rocks, it is given up more readily than by clays, hence a large bore is less necessary. This is fortunate, for the range of size in rock wells is usually rather scant, owing to the fact that most rock wells are of the drilled type. Where the water occurs in bedding or joint planes the diameter is of still less importance, as the entrance of the water is localized and is relatively free. Large diameters, nevertheless, increase materially the likelihood of striking an opening. In the oil regions the increase of the diameter of

a bore 2 inches by reaming has been known to open pools not encountered in the original hole, and a similar result is possible in water wells.

The depth of dug wells in material in which the amount of water is relatively small is also important, for increase in depth increases the storage space in which the water can collect during periods when the well is not in use, thereby greatly adding to its total capacity.

In many regions, owing to the removal of the forests and the construction of drainage ditches, the water from rainfall and snowfall runs off more rapidly than formerly and much less sinks into the ground. As a result the ground-water level has been lowered over large areas, and wells which once afforded good supplies are now dry. In many places there is still plenty of water in the ground, the only difference being that its level has sunk below the bottom of the well. In such places the deepening of the well brings complete relief.

Protection of Dug Wells. — Many open wells are exposed to the same danger of pollution from surface wash as springs, and the same methods of protection should be used. A water-tight curb should be raised a few inches or a foot above the level of the surrounding surface and the earth banked around it, with a slope away from the well. This curb quickly deflects the water and prevents it from collecting and soaking through the ground into the well.

The chief means by which wells become polluted by stock is through seepage from the surface. Watering troughs are commonly placed close to wells, and usually in such places the hoofs of the animals soon wear holes in which the rain water and more or less of the animal excrement collect and soak into the ground, finally reaching the well. To prevent this contamination the watering trough should be placed as far away from the well as possible, the water being conducted to it by pipes. A well in an open pasture, if it is to be used at all by human beings for drinking water, should be surrounded by a fence at least 20 feet away.

The drip from pumps is a very common and dangerous source of pollution. In the greater proportion of dug wells provided with pumps the well is covered with boards or planks laid or nailed over the top. No matter how carefully these platforms are constructed cracks through which water can enter almost invariably exist, and it is a common occurrence to have the water dropping or trickling back into the well whenever any is spilled in pumping. The danger of this will be understood when it is recalled that those stepping upon the platform to pump may have just come from the barnyard or from manured fields, bringing with them on their shoes more or less filth, part of which is left on the planking and washed into the well by dripping water from the pump or by the next rain. The wooden platform should be replaced by a water-tight cover made of iron, cement or other impervious material. Cement covers are coming into use in many localities and afford ideal protection.

An ever-present cause of pollution in open wells and wells insufficiently protected by coverings is the entrance of small animals. It is a common thing for snakes, toads, mice and even rabbits to penetrate through crevices and to fall into the well, especially in dry seasons when the animals are compelled to make desperate attempts to reach water. The remedy is an impervious well cover fitted tightly to the curb.

Dust is usually less dangerous than other sources of pollution, but in dry seasons, when dirt from the street or barnyard is being blown about, it may become of considerable amount and danger. It is not uncommon to find several inches of black, foul-smelling silt in the bottom of a well on cleaning, even though it may have been cleaned only a year or two before. The dust may be kept out by water-tight coverings such as are used to keep out pump drippings.

Seepage through the curb of a well at points above the water level is one of the most frequent and most dangerous sources of pollution. The slight thickness of soil through which the water has percolated and the brief interval required for the passage

through the ground precludes any effective filtration or purification, and the seepage entering the well will carry with it in practically unmodified form any polluting matter it may have picked up at the surface or in the surface soil. As a prevention it was often formerly the practice to surround the outside of the stone curb with a layer of puddled clay, but the more common treatment at the present time is to lay the portion of the curb above the water level in cement.

Cleaning the Well. — In the course of time the material entering the well as dust at the top, or washed in through the ground, forms a considerable accumulation of silt in the bottom and on the sides. In some wells this deposit is sufficient to hinder, to a certain extent, the entrance of water into the well and to lessen its storage capacity. Some relief is usually afforded by cleaning out the well.

In deep dug wells, especially those that have been kept tightly covered, dangerous gases sometimes collect, and lives are not infrequently lost by descending such wells too soon after they have been opened. Carbon dioxide, one of the commonest of the gases found in wells, may be detected by lowering a lighted lantern to the bottom of the well, the flame being extinguished if the gas is present in dangerous quantities.

CHAPTER XII.

BORED AND PUNCHED WELLS.

Advantages and Disadvantages. — Bored wells, which include those sunk with various forms of earth augers, and punched wells, sunk by dropping slit steel cylinders, together constitute a type intermediate between the dug well and the driven and drilled wells (Fig. 35). The larger of the bored wells are closely related to the dug wells, inasmuch as they are commonly fitted with pervious curbs, and many of them differ only in size and method of removing the earth. The smaller bored wells, and most of the punched wells, on the other hand, are provided with tight casings, and are more nearly related to wells of the driven or drilled types.

A summary of the good and bad features of bored and punched wells is given below.

Bored wells (Arkansas type, 2 to 12 inches in diameter, tight casings).

Advantages.	Disadvantages.
Ease of construction; only hand or horse power usually required; skilled labor not essential in shallower holes. Cheapness for moderate depth. Deeper wells little affected by drought. Pollution shut out if properly cased. Gives good records of materials penetrated and water beds encountered.	Limitation to soft materials. Not adapted to very deep wells. Utilizes only one stratum in most places. Other disadvantages similar to those of drilled wells.

Punched wells.

When provided with pervious curbing the advantages are similar to those of open and Iowa type bored wells; when provided with tight casings the advantages are similar to those of the Arkansas type bored wells.	Similar to those of open wells and the larger type of bored wells. Difficulty of operation; liability of crooked holes. Usual limitation to depths under 50 feet. Limitation to soft yet stiff materials, which are generally of local distribution.
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Bored wells (Iowa type, 1 to 3 feet in diameter, pervious curbing).

Advantages.	Disadvantages.
<p>Ease of construction; only hand or horse power required. No expensive materials required for curbing. Cheapness. Utilization of all water strata where curbed with uncemented tile. Utilization of small seeps.</p> <p>Quick response to rainfall.</p> <p>Considerable storage capacity. Accessibility of larger types for cleaning.</p>	<p>Slowness of method as compared with driving.</p> <p>Special outfit required for all but small shallow holes. Limited to soft materials. Ease of entrance of polluting matter through curb and over top. Limitation of points of entrance of water to top and bottom with many wooden curbs. Wood curbs favor development of bacteria. Water, not being replenished, is often stagnant in larger bores. Failures frequent in droughts. Necessity of location at distance from house to insure safety. Necessity of frequent cleaning; danger from gas while cleaning in the larger types. Limitation of practicable depth of large bores. Limitation of size. Short life when curbed with wood.</p>

Location and Protection of Bored and Punched Wells. — Since, in the larger bored wells, the methods of curbing, the manner of entrance of the water supplies and the mode of penetration of pollution are the same in all essential particulars as in the common dug well, it follows that the same rules as to location and protection (see pp. 76 to 84) will apply. Likewise, the location and safeguarding of the smaller, tightly cased bored wells and the punched wells will fall under the rules laid down for driven and drilled wells (pp. 98 and 108) and need not be further discussed at this point.

Sinking the Bored Well. — For sinking the small bored wells, including those of from 2 to 3 inches in diameter, a common carpenter's auger (Fig. 36, 3) welded to a rod or pipe fitted at the end with a wooden handle passing through a plumber's "T" (for the purpose of turning and lifting the auger) is frequently used (Fig. 36, 1). The centering point is usually removed, as shown in the illustration, as it is found a hindrance rather than a help in boring.

Another common type of auger has the form of a spiral coil. It is made of tire iron, welded or riveted to the turning rod at the top, and provided with a cutting edge at the bottom (Fig. 36, 2). It is more efficient than the preceding form, but is more expensive to construct, and requires more power to operate. Owing

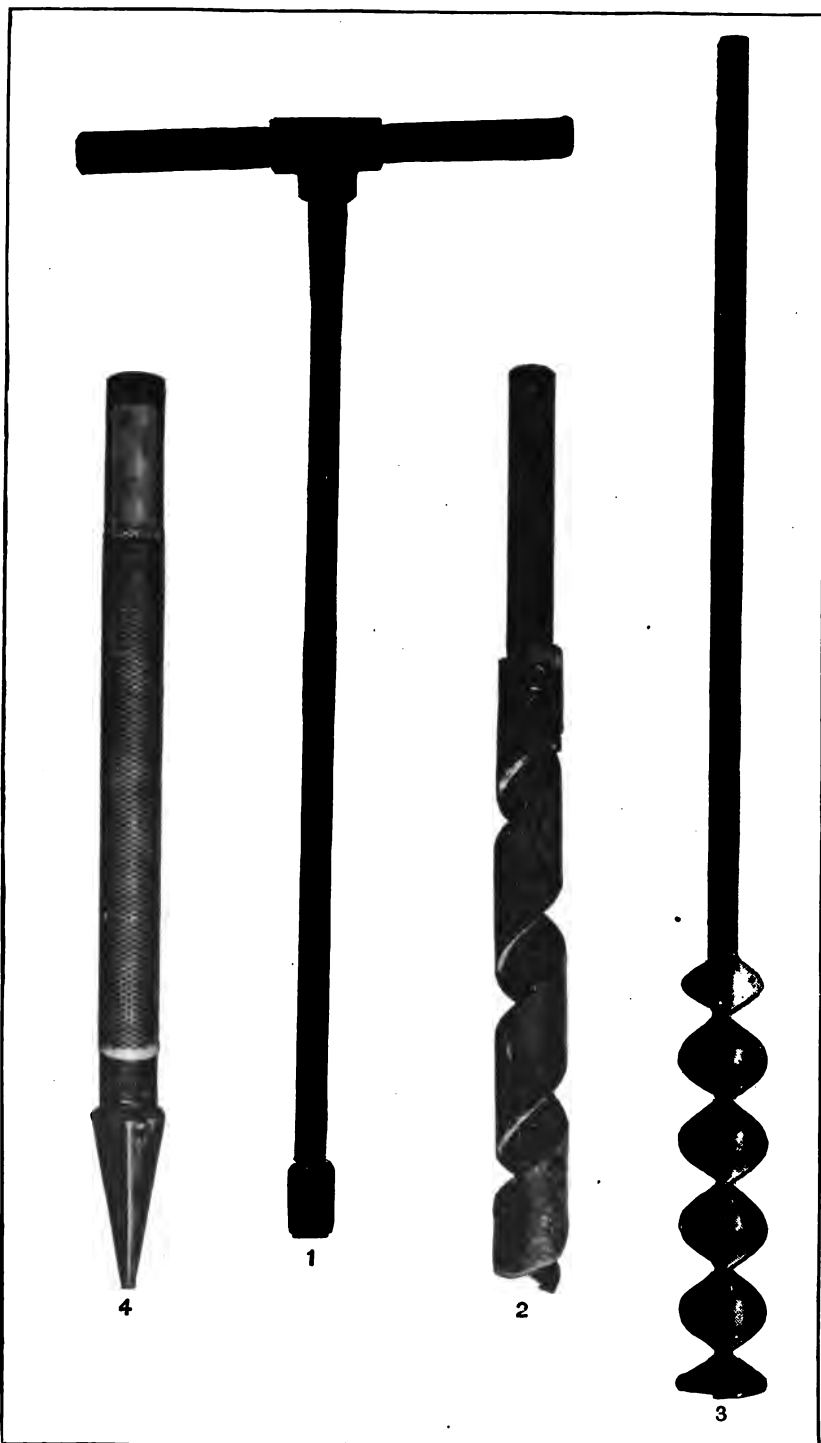
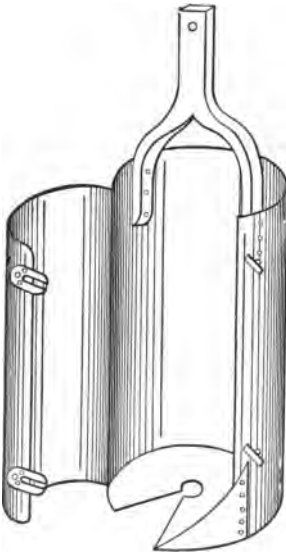


FIG. 36. — Drive point and well augers. 1, turning handle; 2, 3, well augers; 4, drive point and screen.

to the considerable weight of the earth lifted, a windlass or some form of tackle is sometimes required to lift it to the surface. It may be necessary to pour water into the hole to give sufficient coherence to the materials to cause them to cling to the auger.

For medium-sized wells, larger forms of the same general type are frequently used, augers of the standard shape with diameters of 6 or 8 inches being not uncommon. In general, however, special forms, similar to those described in the following paragraph, are used.

For boring wells of large size, from 6 to 36 inches in diameter, some one of the various patented forms are generally used. The common shapes are illustrated by Figures 37, 38 and 39. The method of work is shown by Figure 40, while a special form of bit for lifting boulders is illustrated by Figure 41. Numerous other forms are in use locally.



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FIG. 38.—Common form of well borer.

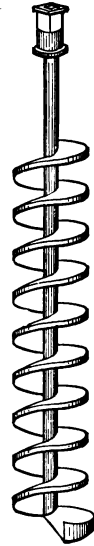


FIG. 37.—Common form of well auger.

The 2- and 3-inch wells are usually equipped with $1\frac{1}{2}$ - or 2-inch-iron pipes, leading from the surface to a point a few feet below water level. Where the material in which a well ends is coarse enough so that it will not clog the pipe, a number of small holes are drilled near the lower end to facilitate the entrance of the water. On pumping, the finer material is raised with the water through the pipe until the remaining coarser particles form a natural filter around the pipe. Pebbles are sometimes inserted through the pipe to aid nature in forming such a strainer. (Fig. 42). In finer materials, a screen is often necessary (Fig. 36, 4),



FIG. 39. — Form of well borer.

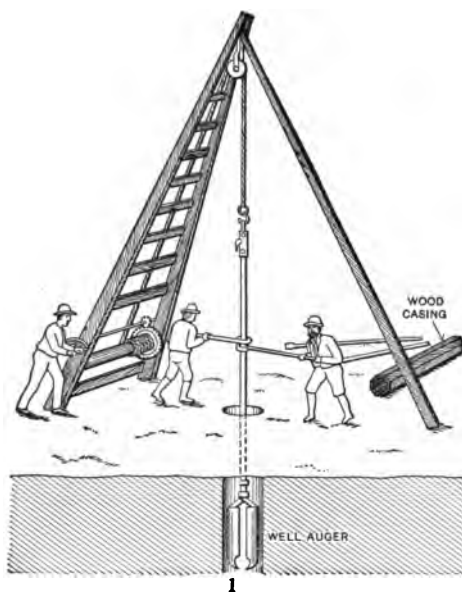


FIG. 40. — Method of using well auger.

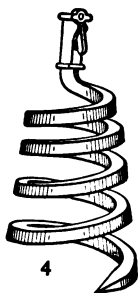


FIG. 41. — Special well auger for lifting boulders.

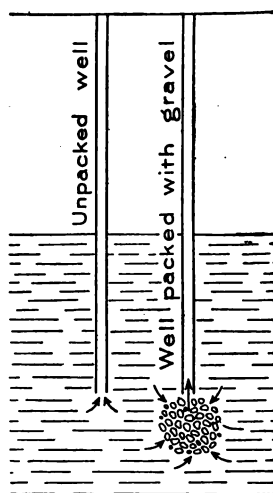


FIG. 42. — Diagram showing advantages of packing with gravel.

but its use is often objectionable because of the ease with which it becomes clogged.

The larger bored wells are often equipped with wooden casings (Figs. 35 and 40) which are driven down by wooden maul. This type of curb has many disadvantages (see table, p. 70), and tile or cement casings are to be preferred whenever they are obtainable. All joints lying above water level should be tightly cemented.

Sinking Punched Wells.— This type of well is most common in regions of coherent soils such as the clays of Louisiana, Arkansas, etc. The apparatus is described by A. C. Veatch as a cylinder of steel or iron from one to two feet in length, split along one side. The lower portion is slightly expanded, sharpened and tempered into a cutting edge. In use it is attached to a rope or wooden poles, and is lifted and dropped in the hole by means of a rope given a few turns around a windlass or drum. By this process the material is forced up into the bit, slightly springs it, and is so held. Water is sometimes added when drilling in dry materials to aid the bit in "picking up." Sand layers are passed by throwing clay into the well and mixing it with the sand until the drill bites.

The diameters of punched wells are usually only a few inches, and their casing and pumping equipment is commonly similar to that of the small bored wells. Wood casing is occasionally used in the larger holes, which are sometimes as much as 6 inches in diameter.

Depths of Bored and Punched Wells.— The boring (auger) process is best adapted to shallow wells, from 20 to 30 feet in depth, but is commonly used to depths of 50 feet. It is carried to greater depths with difficulty and is seldom used where the water is more than a hundred feet from the surface.

In the smaller bored holes, the diameter of the boring is commonly insufficient to admit of the insertion of a pump cylinder, hence the depth to the supply must not exceed that from which water can be conveniently lifted by suction, or about 25 feet.

The limitations of the smaller punched wells are similar to

those of the small bored wells. Larger punched wells are sunk to depths of 50 feet, but the inherent difficulties of the process hinder its use at greater depths.

Cleaning Bored and Punched Wells. — The small diameter wells, if they become fouled, can sometimes be cleaned by hard and continued pumping. If this fails the pipe must usually be withdrawn, taken apart and the material removed. The trouble will be commonly found to lie in the strainer, which will often have to be replaced.

Accumulations in the larger bored and punched wells may commonly be removed by inserting an auger of the proper size and type. That shown in Fig. 38 is well adapted to this purpose.

CHAPTER XIII.

DRIVEN AND JET WELLS.

Extensive Use of Driven Wells. — Driven wells, which are sunk by forcing iron pipes, equipped with points (Fig. 36, 4) at the end, into the ground by blows at the top of the pipe, are exceedingly common in the United States as well as in other parts of the world. They are found in the sand and gravel terraces along our principal rivers, in the sandy and gravelly glacial deposits, throughout the great area of soft sediments along the Atlantic and Gulf coasts and Mississippi Valley, and elsewhere. Abroad, they have been used in army camps at many points, being frequently known as Abyssinia wells because of their extensive use in the Abyssinian campaign of 1895.

Advantages and Disadvantages of Driven Wells. — From the fact that they may be quickly sunk, that they are relatively cheap and that the tight casings, carried to or below the water level, shut out polluting matter, it follows that the popularity of these wells is deserved. They possess, of necessity, however, certain drawbacks. These are indicated, together with their merits in the following table.

Driven wells.

Advantages.	Disadvantages.
Ease of construction; often sunk in a few hours; only hand or horse power usually required. Outfit is inexpensive, can be quickly put up, and does not require skilled labor. Tubing is readily obtainable and inexpensive. Cheapness.	Limitation to soft materials. Utilization of a single water stratum.
Safety; can be located near sources of pollution if sunk through impervious bed preventing access of contaminating matter to water bed; nothing can enter at top.	Usual limitation to moderate depths. Restriction to open porous water beds due to absence of storage facilities. Slow response to rainfall as compared to many dug wells. Corrosion of pipes or screens. Incrustation of pipes and screens.
Permanency of supply as compared with dug wells.	Entrance of quicksand through screens.
Cleaning seldom necessary as compared to open wells.	Taste of water due to solution of the iron under certain conditions. Difficulty of cleaning in case of clogging. Short life as compared to some dug wells. Absence of information as to minor water beds or materials penetrated.

Location of Driven Wells. — Since the wells of the driven type are tightly cased from the pump at the surface to the water-bearing layer below, it is manifest that there can ordinarily be no entrance of polluting matter either at the top or by seepage through the sides.

Since contaminating matter can enter only at the bottom of the well it must previously filter through a thickness of material equivalent to the full length of the pipe; and, as wells of this type are commonly sunk only in sands and gravels, both of which are naturally good filters, it follows that unless polluting matter is carried into the ground in large quantities there is relatively little danger of contamination in wells of this sort. It has been found that in spite of exceedingly unsanitary surroundings of wells of this type in many sandy districts, the waters were reasonably safe.

In fact, except in villages where the whole upper part of the ground-water body is polluted, there is comparatively little danger of contamination if the casing is carried to a point below the polluted zone. Experience has shown that this zone is usually of no great thickness and a well drawing its supply from ten feet below the ground-water level will often prove safe where one just reaching the water-table would be dangerously polluted.

A driven well with its strainer 15 feet below water level (when the latter is at its lowest point) will be practically free from danger; and, if it can be carried to this depth, its exact location will generally be immaterial, and it may be placed where most convenient.

Sinking the Driven Well. — The pipe, which is commonly from 1 to 3 inches in diameter and provided with a driving point at the end, is usually driven into the ground by a wooden or iron maul, operated either by hand or by power. In the larger and deeper wells a heavy weight, operated by a revolving drum and hoisting sheave, or by various horse-power appliances, is used. Additional lengths of pipe are screwed on to the preceding sections from time to time until the required depth is attained.

Ordinarily, especially when the depth of the water-bearing stratum is unknown, a screen (Fig. 43) is inserted between the drive point and pipe, and the well is tested from time to time by a suction pump screwed to the top of the pipe (in case of shallow



FIG. 43. — Types of screen and well points.

wells) or by deep well pumps inserted within the outer tube (in case of the deeper and larger wells).

When a satisfactory supply is reached the well is generally subjected to heavy pumping for several hours to draw from the strainer and the surrounding materials the finer materials, clay, etc., leaving a natural filter surrounding the screen as shown in Fig. 44.

If the screen is clogged by sand or clay that cannot be removed by ordinary pumping, water is sometimes forced down the well to carry the material out into the surrounding soil. Another

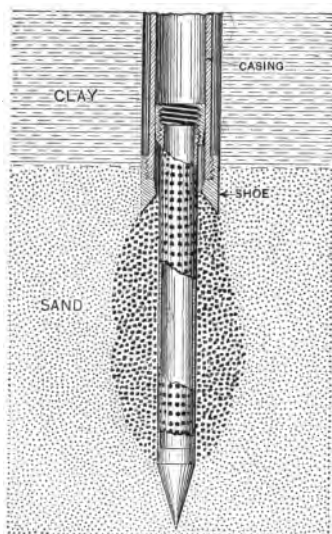


FIG. 44.—Diagram showing formation of sand filter through pumping.

method of avoiding the difficulty is to drive the pipe without screen, and with a loosely fitting drive point. On reaching water, the pipe is withdrawn a short distance, while the screen, which has been previously lowered through the casing, is simultaneously pressed upon the shoe or drive point which remains behind. The withdrawal of the outer casing is stopped as the top of the screen is reached, and the well left in substantially the same condition (except that there has been no clogging of the screen due to driving) as if the screen had been sunk in the usual way.

An advantage of screens inserted in this manner is that they may, if the materials are fairly coherent, be withdrawn for cleaning or replacement, but there is the disadvantage that no tests of quantity of water can be made during the process of sinking.

A simpler method is to use a pipe that slips down over the screen and rests on the point during the process of driving. The pipe can be withdrawn a little at a time and the well tested by pumping, after which, if water is not found, driving may be resumed. The danger, under this method, lies in the fact that in pushing forward the casing over the screen the latter is likely to be torn and ruined by pebbles ground into it by the advancing pipe (Fig. 43, 1).

Depths of Driven Wells. — Driven wells are best adapted to sandy or similar materials where the water rises to within 25 feet of the surface, but they are, nevertheless, very common in many

regions where the water is found as much as 50 feet below the surface, and they are sometimes successfully extended to depths of 250 or 300 feet, or even to 400 or 500 feet or more where the materials are easily penetrated and other conditions are favorable. As previously stated it is always advisable to carry the well from 10 to 15 feet or more below the point where water is first encountered.

Cleaning and Care of Driven Wells. — If the water reached by a driven well contains much iron a crust will commonly accumulate in the screen and rapidly reduce or even cut off the inflow. Sometimes the portion of the incrustation on the inside of the casing may be jarred off by pounding sharply on the top of pipe, but if on the outside, as is more commonly the case, the screen will have to be removed.

If the case is taken in hand in time, the removal of the screen presents few difficulties, but in some parts of the country the accumulation of incrustants, especially those of lime and silica about the screen is very rapid; and often, almost before its presence is realized, it has reached so great a thickness that the removal of the screen through the casing is found to be impossible. The whole casing then has to be pulled up, a new screen substituted, and the pipe replaced, an operation costing about as much as a new well.

It has been found that wells 4 inches or more in diameter seldom require a screen in sandy deposits (except when the pumping is severe), and their substitution for the 2-inch wells, which must nearly always be screened, will afford relief from incrustation troubles in most farm wells. Wells with screens lying entirely in gravel give little trouble from incrustations compared with those stopping in strata in which clay is mixed with the sand or gravel. Where the amount of clay is comparatively small, prolonged pumping at the outset will remove much of it from the vicinity of the screen, and subsequent trouble is to a considerable extent avoided. Artificial pockets of gravel, etc., are sometimes formed about wells by introducing such material through the casing before the setting of the screen (Figs. 42 and 44).

Corrosion of pipes is also frequently an irritating feature of driven wells, even galvanized pipes being at times attacked with great rapidity. The remedy is discussed in the chapter on Special Problems.

Advantages and Disadvantages of Jet Wells. — The chief advantage of the jet or jetting process of sinking wells is its extreme rapidity, the water current and drill coöperating in loosening the material ahead of the casing and permitting the latter to be sunk more rapidly than by any other method. Wells of 400 to 500 feet in depth are sometimes sunk, cased and cleaned in two days. The chief disadvantage is probably the fact that it requires a previous supply of water to operate, a supply that in desert regions is by no means always available. Other advantages and disadvantages are indicated below.

Well sunk by jet process.

Advantages.	Disadvantages.
Rapid in soft materials; operates continuously. Cheap compared with hydraulic, hydraulic rotary, and drilling methods. Supplies inexpensive and readily obtainable. Adapted to incoherent materials, such as sand, not capable of standing alone. Affords fair records and samples of materials penetrated. Other advantages similar to those of driven wells.	Limited to soft materials. Requires more apparatus than driven wells; requires skilled labor. Requires previous supply of water. Small water seams not readily recognized. Draws from single water bed. Requires strong water beds due to absence of storage facilities; seeps can not be utilized. No storage capacity. Usually limited to small diameters. Satisfactory only in wells of moderate depth. Slow response to rainfall as compared to shallow dug wells. Corrosion and incrustation of pipes. Taste of water due to solution of iron by corrosive waters. Difficulty of cleaning.

Location of Jet Wells. — The jetting process is particularly adapted to the finer types of unconsolidated deposits, such as sands, etc., the materials of which are easily displaced and lifted by the water current. It has been extensively used in the coastal plain deposits along the Atlantic, in many inland glacial deposits, and in some of the alluvial valleys of the West, especially in California.

In general, the statements made as to the location of driven wells apply equally to jet wells, since the two forms of wells are

essentially the same after completion. The reader is referred, therefore, to the discussion of the wells of the former type (p. 98).

Sinking Jet Wells. — The jetting outfit consists of an iron casing, a drive weight for sinking the casing, a hollow bit attached to a drill pipe and working within the casing, a water swivel and a force pump for forcing water down the drill pipe and out through the drill. The smaller wells are commonly sunk by hand power as shown in Figure 45, but larger wells require masts and hoisting sheaves, with engines to furnish power for handling the pipe and operating the pump (Fig. 46.)

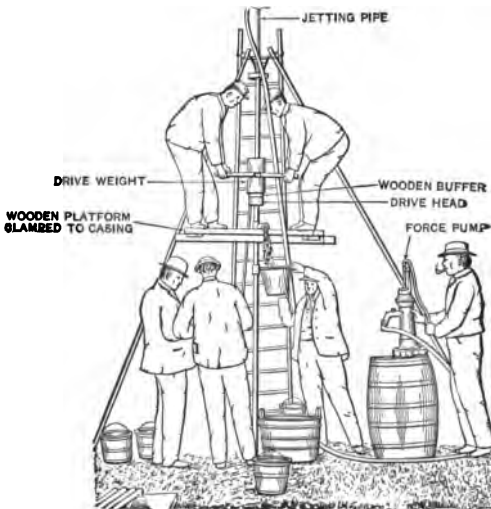


FIG. 45. — Diagram showing method of sinking jet wells by hand.

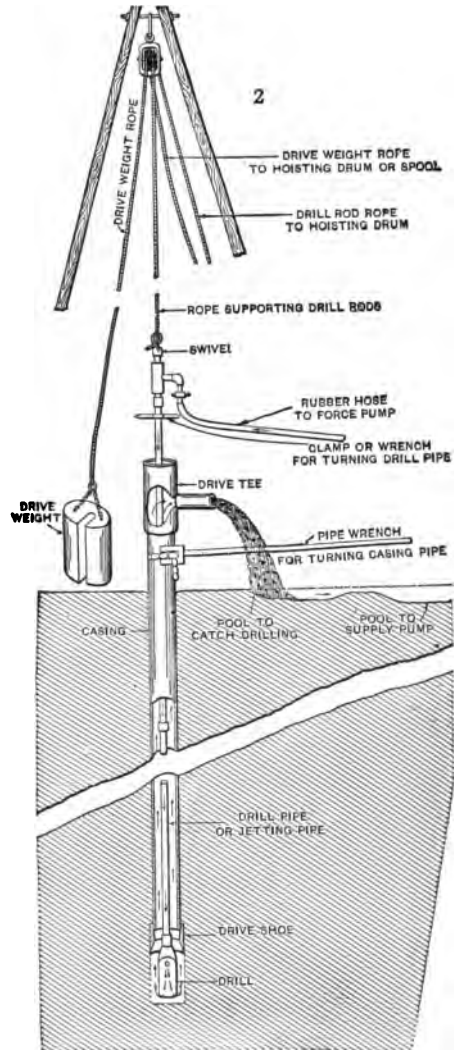


FIG. 46. — Diagram showing outfit and process of sinking deeper jet wells.

In the smaller wells a common diameter for the casing is $2\frac{1}{2}$ inches, while the drill pipe usually has a diameter of 1 inch. The

water is forced downward through the drill pipe and hollow bit (Fig. 47), and loosens the material about the bottom of the well, the finer portion being carried to the surface by the current ascending between the drill pipe and the casing.



FIG. 47. — Hollow bit used in jet process.

The bit is turned slowly during the process to increase the rapidity of sinking and insure a straight hole. As fast as the bit advances, it is followed by the casing, which sometimes, as where a paddy or expansion drill (Fig. 48) has previously been used to ream out a hole larger than the casing, sinks under its own weight. More commonly, however, a drive weight (Figs. 45, 46)

is used to force it down. The same size casing is, as a rule, used from top to bottom of the well.

Hard layers are penetrated by substituting an ordinary drill for the hollow bit, the former being lifted and dropped as in the standard percussion methods. In clayey or other coherent materials the walls will sometime stand alone, and the casing may not be inserted until after the hole has been jetted to its full depth.



FIG. 48. — Paddy or expansion bit used for reaming.

Depth, Size and Care of Jet Wells. — Jet wells are usually sunk only when it is necessary to go less than 100 feet, but this is a limitation of practice rather than a limitation of possibility, for wells of the jet type have been successfully sunk in California to depths of over 600 feet, and by reducing the size of casing at a point from 500 to 600 feet below the surface, considerably greater depths may be attained. Common diameters of the casings for depths up to 150 feet are 2 and 3 inches; for wells that are to be sunk to depths of 400 to 600 feet, 4-inch casing is most common.

The jet wells are not usually provided with strainers, hence they avoid many of the troubles due to the incrustation of the screens. Incrustations within the pipe and corrosion of casings are treated as in the case of driven wells.

CHAPTER XIV.

DEEP WELLS.

Types of Deep Wells.—The preceding types of wells have all been of comparatively simple forms requiring relatively little in the way of apparatus for their sinking. In many instances they can be sunk without special difficulty by the farmer himself or by local drillers.

Types of deep wells and conditions to which they are adapted.

Type of well.	Description.	Conditions to which well is best adapted.
Standard drilled.....	Sunk by percussion of heavy drill, 1½ to 12 inches or more in diameter, lifted and dropped from portable rig or derrick by horse or steam power. Cased with iron pipe in soft materials; usually not cased in rock. Drillings removed by long bucket with valve in bottom.	Can be used to advantage in all but the softest materials, but is particularly adapted to rock work, especially at great depths, being cheaper and quicker than other methods of drilling in rock.
Diamond-drill hole.....	Sunk by rotating hollow bit, usually 1½ to 4 inches in diameter, with rim fitted with black diamonds. Penetrates by abrasion due to rotation. Drillings removed by water forced down drill and up along outside of rods.	Not adapted to water wells because of great cost. Used where cores of materials penetrated are required, or where hole is sunk at an angle with the vertical.
Wells sunk by calyx and steel-shot methods.	Sunk by rotation of notched steel shoe, or by chilled steel shot used in connection with a rotating plain shoe of soft iron. Rods by which power is transmitted are hollow and permit the dropping of the shot and the entrance of water, which brings up the cuttings as with the diamond drill.	Adapted to vertical work in hard rocks where cores are required. Cheaper but slower than diamond-drill method, and more expensive than standard drilled holes. Is successfully used as an adjunct to hydraulic rotary process.
Wells sunk by hydraulic process.	Sunk by lifting and dropping drill in hole full of water. Penetrates by percussion. Water and cuttings are forced into hollow rod on down stroke, being retained by valve. Diameter similar to standard drilled wells.	Adapted to clays and other unconsolidated deposits and to soft rocks where depths are moderate and the use of a heavy drill is not required.
Wells sunk by hydraulic rotary process.	Sunk by rotating steel shoe, as in calyx method, but with the difference that whole pipe is turned and water is forced down pipe and up outside instead of through rods. Steel shot also sometimes used.	Adapted to rapid work at considerable depths in materials prevailing soft, but having occasional hard layers.
California or stovepipe.	Overlapping sheet-steel casings, 4 inches or more in diameter, forced downwards by hydraulic jacks and finally perforated by a special apparatus at water strata. Drillings are removed by a long sand-bucket with valve.	Adapted to soft materials extending to considerable depths and having several water strata capable of utilization.

The deep wells, on the other hand, generally require elaborate outfits, with trained men for their operation. Complicated problems, far beyond the ability of the ordinary farmer to handle, are

constantly encountered, and the services of a professional driller are usually essential. Detailed descriptions of the types of wells and technical explanation of the drilling methods would, therefore, be of little value to the farm owner.

The character of the different forms of deep wells are indicated in the table on page 105, together with the conditions to which they are best adapted.

Advantages and Disadvantages of Different Types of Deep Wells. — All deep wells possess the advantage of drawing on supplies that are usually far below the limits reached by pollution. The majority are cased through the surface soils and for at least several feet into the rocks, which commonly prevents contamination from shallow sources. Furthermore, the supplies, though perhaps no greater than those of many relatively shallow wells, are likely to be more steady and less affected by droughts.

On the other hand, deep wells are expensive to drill and the water is commonly more mineralized than that of shallow wells, although the reverse is true in many of the alkaline regions of the West, and also in localities where the shallow waters are from clayey or marly materials while the deep supplies are from sandy foundations.

The special advantages and disadvantages of the individual types are brought out in the accompanying tables.

Summary of advantages and disadvantages of different types of deep wells.

Standard drilled wells.

Advantages.	Disadvantages.
<p>Adapted to all rocks.</p> <p>No ordinary limitation as to depth. Can be readily deepened. Little affected by droughts. Can utilize all water strata where there is no great difference in head if casing is perforated, but this is rarely done. Pollution is completely shut out if properly cased. Can be located anywhere. Gives fair records of materials and water beds encountered.</p>	<p>Expensive; requires elaborate outfit, skilled labor, steam power with the attendant charges, and costly casing and pumps in deeper wells. Many difficulties in drilling; frequent losses of tools. Cleaned with difficulty.</p> <p>Slow response to rainfall; slight storage capacity.</p> <p>Corrosion of pipes and screens. Incrustation of pipes and screens. Entrance of sand through screens or clogging of screens.</p> <p>Taste of water due to solution of iron under certain conditions.</p>

Diamond-drill holes.

Advantages.	Disadvantages.
<p>Gives complete core of rocks penetrated. Can be drilled at any angle.</p> <p>Other advantages similar to those of other drilled wells.</p>	<p>Adapted only to hard rocks. Requires costly outfit and materials, skilled labor, steam power, etc. Cost greater than drilled wells.</p> <p>Other disadvantages similar to those of drilled wells.</p>

Wells sunk by calyx and steel-shot method.

<p>Outfit and cost of sinking less than in diamond-drill holes.</p> <p>Readily used in connection with hydraulic-rotary rig when hard rocks are encountered. Other advantages similar to those of drilled wells.</p>	<p>Both outfit and cost of operation more than in drilled wells.</p> <p>Slower than diamond drilling.</p> <p>Other disadvantages similar to those of drilled wells.</p>
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Wells sunk by hydraulic process.

<p>Rapid in soft materials. Can be used where soft and hard beds alternate, but works best in uniform materials. Penetrates hard beds by fall of drill. Operation nearly continuous. Affords good records. Other advantages similar to those of drilled wells.</p>	<p>Usually limited to relatively small diameters. Requires previous supply of water for drilling process.</p> <p>Other disadvantages similar to those of drilled wells.</p>
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Wells sunk by hydraulic rotary process.

<p>Very rapid in soft materials. Applicable to alternations of soft and hard material. Operations are relatively continuous; little lost time. Can penetrate hard beds by use of calyx appliance and chilled-steel shot.</p> <p>Other advantages similar to those of drilled wells.</p>	<p>Satisfactory only where the materials are prevaillingly soft. Small water seams not readily recognized; shut off by puddling by thick sludge. Requires previous supply of water for process of sinking well. Affords unsatisfactory records.</p> <p>Possible for polluting matter to penetrate by passage through loosened zone along casing. Other disadvantages similar to those of drilled wells.</p>
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Stovepipe or California wells.

<p>Utilization of all horizons of water. Cheapness of casings as compared with large-sized driven or drilled wells. Shortness of sections, permitting use of steady pressure by hydraulic jacks.</p> <p>Adaptability to conditions where driving is impossible. Flush outer casings and absence of screw joints. Ready adjustment to strains. Avoidance of clogging of perforations. Exclusion of sources of pollution. Affords fair records of materials and water beds encountered.</p>	<p>Limitation to soft materials. Lack of strength of casing; distortion by lateral pressure; pulled with difficulty if distorted. Thinness of casing and shortness of life where waters are corrosive. Expensive; requires elaborate outfit available in only a few sections of country; skilled labor, etc. Cleaned with difficulty.</p> <p>Slight storage capacity. Taste of water due to solution of iron by corrosive waters. Short life under some conditions.</p>
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Location of Deep Wells. — In the location of deep wells the chief consideration is the obtaining of a supply, slight differences in location seldom seriously affecting the cost, while the prevailing use of casing in soft deposits insures safety from ordinary sources of pollution. The occurrence of deep waters depends on the character and structure of the rocks far below the surface. No indications of these features are usually found at the surface, and the well may as a rule be located independently of surface relief, though where artesian flows are expected the well should be located on as low ground as possible. Information as to the best location for a deep well may often be obtained from a careful study of the records of wells in adjacent regions, which can be made by the more experienced and intelligent drillers, or from a study of the rocks and their structure, which often requires the services of a trained geologist.

Relation of Depth and Supply. — It is a widespread, in fact an almost universal, belief that the amount of water increases with depth and that water may be had anywhere if one only "goes deep enough." This is, however, far from the truth. Rainfall appears to be the source of at least 99 per cent of the fresh water found in the ground, the remainder being water included in the rocks at the time of their accumulation beneath the sea, together with a small amount derived from volcanic sources. As would be expected from its atmospheric source, water actually decreases rather than increases in amount with depth, a great many rocks encountered by the deeper wells and mines, especially at depths below 1000 feet, being entirely destitute of water.

However, if only the more superficial portion of the crust is considered, there is in general an increase of water with depth. Except in valley bottoms and other depressions the surface soil and rocks, although carrying much moisture, are rarely saturated; but at depths which vary, according to climate, soils and topography, from a few to several hundred feet, a saturated zone constituting the ground-water body is encountered. Wells starting anywhere above drainage level will in general encounter water in

increasing amounts at least down to the drainage level. Again, the surface beds may be of non-porous nature and may therefore be destitute of water, while the underlying beds, if porous and below drainage level, are likely to be saturated.

Of course there is a constant tendency for the surface waters to penetrate downward and fill the porous rocks below. That these are at present destitute of water may be due, at least in certain rugged regions, to the draining of the deeper and in places relatively porous beds by deep valleys. Elsewhere, and this is doubtless the most common cause, the water is kept from percolating downward by impervious beds near the surface. The deeper rocks are largely of the granitic type and hold but little water. Except where they constitute the surface rock and are somewhat broken by joints it is of little use to penetrate them in search of water.

To speak broadly, it may be said that there is no general increase of water with depth and that the finding of deep supplies is entirely dependent on local geologic conditions. Unless there is some proof that deep water-bearing beds exist, the sinking of a well more than a few hundred feet in depth should be regarded wholly in the light of an experiment, although in sedimentary rocks it has the decided advantage that it may penetrate a number of water strata, which may afford in the aggregate a fair supply where a single stratum might not suffice.

Relation of Depth and Head. — The relation of head to depth has been discussed in connection with artesian flows (p. 58). It may be said that, while there is no fixed relation between the two, it is perhaps more common than otherwise for the deeper strata of the structural troughs giving rise to artesian flows to outcrop at higher levels than the overlying beds, although the reverse is often true. In many structural basins, the water-bearing beds rise toward the rims and outcrop in plateaus or other elevations high above the low plains over the center of the basins.

Relation of Depth and Quality. — Another prevailing idea is that the deeper waters are purer. Within limitations this is gen-

erally true as regards the shallower waters, which, being close to the surface and without the protection afforded by overlying clays or other impervious beds, are susceptible to pollution. Deeper waters, on the other hand, are almost always overlain by relatively impervious beds that serve to keep out polluting materials, and as a rule they are entirely safe. In many places, however, the amount of mineral matter dissolved in the water shows a general increase with depth, the amount in deep waters averaging several times that in surface waters, which are largely made up of recent rainfall. There are some exceptions to this law, due mainly to variations in the character of the materials in which the waters are found, the waters in a calcareous glacial drift or in an alkaline flat, for instance, often being very much harder than those in underlying beds. Limestone waters, too, are generally harder than sandstone waters. The maxim of certain drillers, "The harder the rock the harder the water," is based on the prevailing softness of the sandstones in many districts as compared to the hardness of the limestones.

Summary Statement. — Contrary to the common belief, there is no general increase in the volume of underground water with increase in depth, such gain in volume as is occasionally found being due to peculiar local conditions. Neither is there a universal increase of head, although it may happen because the lower beds outcrop at higher altitudes than the upper ones (Fig. 32). The deeper waters, however, are generally safer than those near the surface, although their mineral content is likely to be higher.

Protection of Deep Wells. — Many of the conditions favorable to pollution of the shallow wells likewise favor the contamination of deep wells, but as the causes and remedies have already been discussed, especially in connection with the section on "Safety distance," they do not require further consideration at this point.

The water of deep wells when first encountered is usually safe and rightfully has a good reputation, so that people often go to great expense in drilling for deep rock waters. Unfortunately, however, many fail to realize that unless care is taken, it is possible

for deep wells to become polluted by the entrance of surface waters. In regions where the rock is within a few feet of the surface, for instance, the casing may be carried only to the rock, the fact that pollution can enter the well through the rock crevices being entirely overlooked. (See Fig. 49.)

The chief precaution necessary against this danger is to carry the casing to a sufficient depth to shut off all surface waters entering through fissures. It is hard to say how deep it must be carried to remove all danger of contamination, but the crevices are usually limited to the upper part of the rock (Fig. 49),

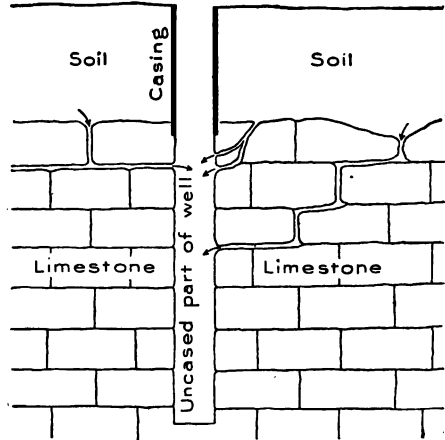


FIG. 49. — Diagram showing danger of pollution where casing is carried only to rock.

and every additional foot of casing gives additional safety. Ten feet of casing in the rock would materially reduce the danger, while 25 feet would in most wells probably insure safety. The safest plan, however, is to carry the casing from the surface down to the water-bearing seam. The casing should always be set with a tight joint at the bottom to prevent the entrance into the well of surface waters that find their way downward along the outside of the pipe.

Again, it is not unusual to drill new wells in the bottom of old dug wells and to allow the polluted surface waters to mingle with the pure rock waters.

Many towns situated on rock surfaces and using unprotected wells of the type mentioned have been visited by epidemics of typhoid fever, cholera and other diseases, leading to the loss of many lives.

Another source of pollution, less common and possibly less dangerous than the preceding, arises from the fact that many

casings are left open at the top, even when care has been taken to carry them to proper depths. Figure 51 shows a casing properly protected, all openings being hermetically sealed by cement.

A fourth and very common means of contamination of deep wells is by leaks in the casing due to imperfect joints or to corrosion. The process of corrosion may be very rapid, the pipe in some wells with acid chalybeate waters lasting only a few years. No one expects a pipe laid in the ground near the surface to last many years, yet many seem to think that a well casing will last indefinitely. Unfortunately, this is far from true.

When the casing has been corroded, pollution from sources near the surface is often admitted through the minute holes eaten in the iron, spoiling the deep waters. Where the casing does not entirely fill the hole, contamination may pass down outside of it, while in uncased rock wells pollution may enter through any of the numerous fissures that usually exist in the upper part of the rocks. Even in such wells, however, the danger of contamination decreases rapidly with depth.

The detection of leaks is somewhat difficult. In some wells, however, water may be heard trickling in or may be seen by a light ray projected down the well by a mirror when the pump is withdrawn. The admixture of water from outside sources may sometimes be detected by a change in the hardness of the well water, by an earthy taste or taste of decayed vegetation, or by a cloudiness due to silt brought in by superficial waters.

The remedy is usually to pull the old casing and replace it by a new one, the length of time the pipe is allowed to remain before replacement being determined by an estimate of its life based on the action of the water on the pump tube or other pipes. An alternative treatment sometimes employed when the leak is near the surface is to set a packer designed for the purpose in the space between the bottom of the pump tube and the casing and fill the space above with cement.

CHAPTER XV.

SPECIAL PROBLEMS.

Shooting. — The practice of “shooting” — exploding a charge of nitroglycerine or other explosive in a well — has long been successfully employed in the oil regions, and has in late years been used to increase the flow of water wells, in which dynamite is more commonly used. The action of the dynamite is to shatter the surrounding rock, with the result that connection is frequently established with other crevices, in some wells largely increasing the water supply. The dynamite is most effective in hard, brittle rocks, such as limestone, which are as a rule completely shattered by the explosion, and is least effective in soft tough shales, which are bent and compressed rather than broken.

Use of Steam Jet. — Shooting, owing to the character of the materials, is not usually practiced in unconsolidated deposits, in which the steam jet is sometimes used instead of dynamite. The steam is forced down a small pipe inside a larger one and, coming into contact with the water at the bottom, turns it quickly into steam, the resulting explosion loosening the material or making a pocket about the bottom of the pipe. Where the materials are dense and clayey the action of the steam jet may considerably increase the influx of water; in the more porous deposits it has less effect.

Screening the Well. — Wherever the well is sunk in unconsolidated materials in which the grains are small enough to be moved by the water entering the well, the use of some sort of screen is essential. The method of forming a natural screen by pumping the finer particles from amongst the coarser materials at the bottom of the well, of inserting and packing gravel about the lower end of the pipe, and the nature and use of the common

well-point type of screen have already been described in the chapter on driven wells. Other screens, the use of which is not limited to driven wells, are described below.

One of the most common forms of screen consists of an ordinary iron pipe perforated with quarter-inch holes placed about 2 inches apart, the whole being wound with iron wire. The closeness of the winding is dependent upon the fineness

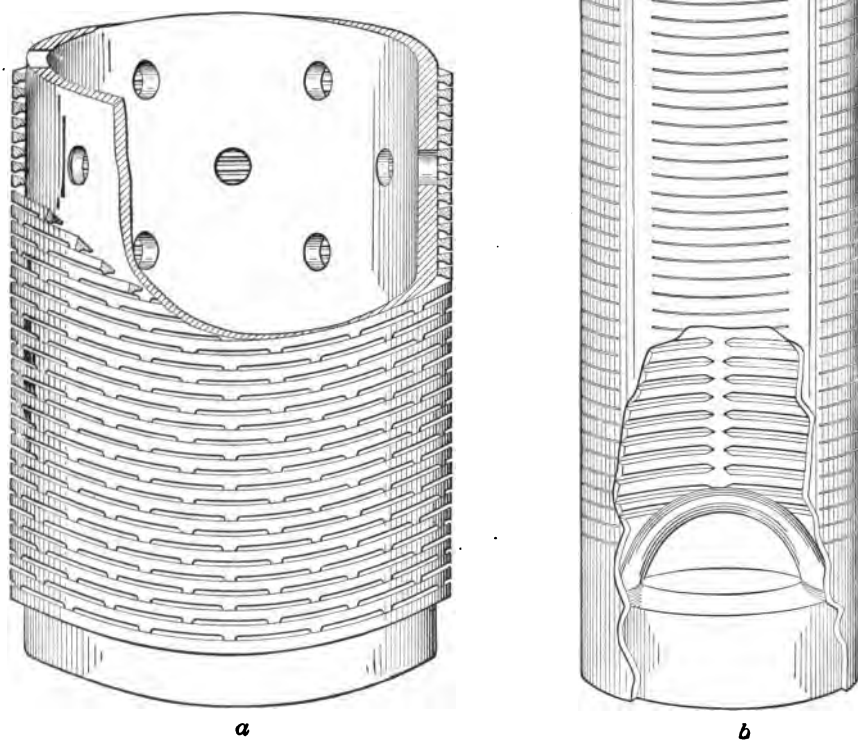


FIG. 50. — Well strainers: *a*, Layne strainer; *b*, Cook strainer.

of the material in which the water is found. Some of the screens of this type are as much as a hundred feet long.

Many waters, such as those of considerable areas of the lower Mississippi valley, rapidly attack all forms of iron or galvanized

iron casings. In such instances, perforated wooden pipe wound with iron wire is often used.

In the California or stovepipe type of wells the casing itself serves as a screen. In drilling, a record of water-bearing strata is kept, and, on completion, a perforator is lowered into the pipe and vertical slits are cut in the thin sheet-steel casing at the desired points. Practically the entire length of casing is sometimes converted to a screen where the well is in a continuous water-bearing stratum.

In clayey materials, quicksands, etc., one of the several types of patented screens or strainers is commonly used. The Layne strainer (Fig. 50 *a*) consists of a perforated tube wound with metal strips (or wire) of triangular cross section, flat side outward, the exterior presenting a flat surface to the sand, reducing the danger of clogging and prolonging the life of the well. The Cook strainer, another popular form (Fig. 50 *b*), consists of a seamless brass tube cut with horizontal slits of varying widths to suit different materials. The outside of the pipe is smooth, but the slits expand towards the inside to permit the free entrance of water while reducing the possibility of clogging to a minimum.

Setting the Casing.—In water wells of the drilled type extending into rock it is almost always desirable to make a tight joint between the casing and the rock, either at the surface of the latter or a few feet lower down, the object being to prevent the entrance into the well of surface waters or polluting matter.

Many drillers count on securing a water-tight contact with the rock by simply driving the casing firmly against the surface, but it is needless to say that the efficacy of such a contact is not to be relied upon. To secure a tight contact the size of the hole should be reduced by substituting a smaller bit. This results in the formation of tapering walls at the point of change, against which the casing may be firmly set.

“Casing Off.”—Where a stratum of caving materials is penetrated or where a flow of objectionable water is encountered it must be “cased off.” Since casing from the surface to the point

of danger would not only be expensive but would also often shut off desirable water supplies, the size of the hole is reduced and a short section of casing (just long enough for the purpose) is lowered into the hole and set as described in the preceding paragraph. Sometimes several strata have to be thus cased off, the size of the hole being necessarily decreased each time, since the drill in further work must be operated through the smaller pipe.

Packing. — Packing consists in forming a water-tight joint between the outside of the casing and the rock, and is necessary to prevent the water from passing upward along the outside of the casing, or to prevent the shallower and perhaps contaminating water from being drawn downward along the casing into the well.

Formerly flaxseed was extensively used, bags being placed at the points where the casings were to be set. The drill was then lowered on the bag, breaking it apart and forcing the seeds into the opening between the pipe and the rock where, in contact with the water, they rapidly expanded and closed the opening.

Cement and asphalt have also been used, but have not been found satisfactory in this country. Here rubber packers, made in a great variety of forms and sizes especially for the purpose, have been found to be most economical and effective. Several forms are so constructed that they may be removed, brought to the surface for examination, and later reset at will.

Plugging. — Plugging means the complete obstruction of the well by the insertion of some material or apparatus designed for the purpose. Wells are usually plugged to prevent objectionable supplies of water, oil, etc., from entering below the higher and better supplies which it is desired to use. The nature of the plug used in water wells is not greatly different from that used in oil wells, which in Ohio is defined by law as "a dry wooden plug not less than three feet in length, equal to the diameter of the hole." Over this, according to the same statute, there must be placed "at least seven feet of sediment or drillings, or cement and sand."

Corrosion of Casings.—Many waters attack casings with great rapidity and destroy them in the course of a few years, sometimes even within a few months, although other casings may last for 10 to 20 years. In general it has been found that the waters attacking the casings most rapidly are those which are highest in carbon dioxide. Such waters attack zinc as well as iron and the use of galvanized pipes affords little relief. Block-tin has been occasionally substituted, but sometimes even this has been eaten through, although it is ordinarily little affected by water. In places, relief has been obtained only when wooden pipe has been substituted, although the life of such piping is short and its use is otherwise objectionable. Of the iron pipes, the common "black iron" type seems to give the least trouble.

CHAPTER XVI.

COST OF DRILLING AND CASING.

Variability of Cost of Wells. — As pointed out on another page (p. 74) the cost of wells is exceedingly variable in different parts of the country, the prices charged depending almost entirely on local conditions. Where the conditions that the driller is to encounter in sinking a well are definitely known, the price is almost invariably lower than where wells are drilled in new territory. Thus, in many of the drift regions of Michigan, where the driller has learned by experience that the materials to be penetrated are likely to present no obstacles to driving, he will in many instances sink a 50-foot well and equip it with a pump for \$15. In Massachusetts, where the driller is less familiar with the conditions, \$1 a foot is often charged for a well drilled in precisely the same type of materials.

In the oil regions, wells are frequently sunk in the shales and sandstones for 75 to 90 cents a foot, although elsewhere \$3 a foot is often considered a fair price for drilling in shale. In granite, the cost commonly varies from \$3 to \$10 a foot, while the usual charge for wells in limestone is from \$50 to \$2 a foot.

Cost of Casing. — The cost of casing, like that of drilling, is quite variable, changing from week to week, according to the quotation for iron, and differing greatly according to length of railroad transportation, haulage, etc.

The smallest size pipes, such as are used in driven wells, commonly range in size from 1 to 2 inches and in cost from 10 to 20 cents per foot. Four-inch casings usually cost from 40 to 50 cents a foot, while for larger sizes the price increases about 20 cents a foot for each increase of an inch in diameter, or up to \$2 a foot for a 12-inch casing.

The casing used in wells sunk by the California or stovepipe method are of riveted steel and come in 2-foot lengths. The prices range from about 35 cents per foot for 4-inch casing up to \$1 for 10-inch casing, varying somewhat with the thickness.

Cost Table for Wells. — The following table indicates in somewhat more detail the prices charged for sinking wells in different localities and in varying materials.

Cost of Wells.

Type.	Material.	Diameter.	Locality.	Remarks.	Cost per foot.
		Inches.			
Open (dug)	Unconsolidated	30-60	Various	Price varies greatly with diameter, depth, and character of curbing.	\$2.00-\$10.00
Open (dug)	Unconsolidated	36	Connecticut	Average of 32 wells.	\$3.10
Open (blasted)	Rock	36?	Maine	Price applies only to relatively shallow wells.	\$4.00
Driven	Sand, etc.	1½-3	Michigan	Price including casing.	\$0.35-\$0.75
Driven	Sand, etc.	2	Iowa and Minnesota	Price including casing.	\$0.50-\$0.75
Driven	Sand, etc.	2	Massachusetts	Price including casing.	\$1.00
Driven	Sand, etc.	2	Connecticut	Average of many wells.	\$0.70
Bored (hand)	Clay, etc.	3-4	Arkansas	Curbing not included.	\$0.25-\$0.35
Bored (hand)	Clay, etc.	6	Arkansas	Curbing not included.	\$0.50
Bored (power)	Clay, etc.	6	Arkansas	Curbing not included.	\$0.12-\$0.40
Bored (power)	Clay, etc.	6-36	Iowa, etc.	Prices are for slight depths, casing not included.	\$0.50-\$1.00
Punched	Clay, etc.	4-6	Arkansas	Curbing not included.	\$0.15-\$0.50
Jet	Sands	4	Arkansas and California	Price is for 400-600-foot wells. Casing not included.	\$1.00
Jet	Sands	2-3?	Louisiana	Shallow. Casing not included.	\$0.30
Jet	Sands	2-4	California	Less than 100 feet. Casing not included.	\$0.30-\$0.40
Hydraulic rotary	Coastal plain deposits. Alternating hard and soft layers.	6-8	Arkansas	Depths of 400 to 1000 feet. Includes casing.	\$2.50-\$5.00
Hydraulic rotary.	Coastal plain deposits. Alternating hard and soft layers.	6-8	Texas	Depths of 400 to 1000 feet. Includes casing.	\$4.00-\$4.50
California stovepipe	Sand, gravel, etc.	4-10	California	Casing not included.	\$0.30-65 for first 100 feet, with increase of \$0.25-0.35 a foot for every 50 feet.
Standard percussion.	Shale	6-8	Pennsylvania.	Casing not included. Depths under 1000 feet.	\$0.75-\$1.00
Standard percussion.	Soft shale	6	Maine	Casing not included. Depths usually under 300 feet.	\$2.00
Standard percussion.	Hard shale	6	Maine	Casing not included. Depths usually under 300 feet.	\$2.50-\$4.50
Standard percussion.	Sandstone	6	Connecticut	Average cost without casing.	\$2.00
Standard percussion.	Sandstone	8	Connecticut	Average cost without casing.	\$2.75
Standard percussion.	Limestone	6	Mississippi valley	Casing not included.	\$0.50-\$1.00
Standard percussion.	Granite	6	Maine	Casing not included.	\$3.00-\$6.00
Standard percussion.	Granite	6	Connecticut	Common range without casing.	\$2.50-\$8.00
Standard percussion.	Granite	6	Connecticut	Average without casing.	\$4.25
Standard percussion.	Trap	6	Washington	Casing not included.	\$2.25-\$3.00
Standard percussion.	Quartzite	6	Minnesota	Average without casing.	\$3.00-\$4.00
Diamond (core)	Moderately hard rocks.	1½	Various	Common cost. Prices much higher for hard rock and deep borings.	\$1.50-\$2.50

CHAPTER XVII.

METHODS OF RAISING WATER.

Common Methods. — Leaving out of account the natural flowing or true artesian wells, the supplies from which are seldom pumped, water is commonly brought to the surface by some one of the several forms of buckets, by various types of pumps, or by the so-called air lift process. To a certain extent, the method of lifting the water is directly dependent upon the nature of the well and the supply demanded.

The ordinary chain pump, for instance, can be used only in open wells of large diameter where only limited quantities of water are required. The valve-buckets are suited only to wells of from 4 to 8 inches in diameter where the quantity demanded is small. Suction pumps are satisfactory only in wells where the water is 25 feet or less from the surface. Deep well pumps can be operated satisfactorily in tubular wells of all sizes over 2 inches in diameter, provided the volume to be lifted per minute is not high. Air lifts are suited to the larger sizes of cased wells in which the volume per minute to be lifted is very large.

Buckets. — The “old oaken bucket” needs no description. Attached to the long sweep, once so picturesque a feature of rural landscape of New England, or to the most prosaic windlass (Fig. 34), it is familiar to every one, and will long hold its own in popular favor in the older and more conservative portions of the country. Nevertheless, since its use prevents the proper protection of the well from the entrance of the dust, animals, etc., it is objectionable and should be replaced by tight coverings and pumps wherever possible.

The valve-bucket (Fig. 35) commonly has the form of a metallic cylinder, usually of galvanized iron, provided with a valve

at the bottom which permits the entrance of water when the bucket is lowered, but which shuts and prevents its escape on being lifted. Its use is confined almost entirely to wood-curbed, bored and punched wells. The diameter is just enough smaller than the inside diameter of the curbing to permit it to be raised and lowered without undue friction. There is nothing inherently objectionable in the bucket itself, though the open top and the wooden curb with which it is associated are to be condemned.

Chain pumps. — The so-called chain pump consists of an endless chain passing over a sprocket wheel at the top, and running through a wooden tube. The chain is equipped at short intervals with rubber or metal disks. On turning the handle attached to the sprocket, it is made to revolve, the water being lifted by the tightly fitting disks as they pass upward through the tube. Much has been claimed of this type of pump because of the aeration of the water produced by the descending disks, but it is very doubtful if the slight aeration brought about is of any material importance. The pumps of this type are commonly enclosed, so that their use is attended by relatively little risk of pollution, provided the well is otherwise properly protected. They are best adapted to shallow wells and cisterns, since the weight of the water in the tube in the deeper wells is considerable. Their cost with wooden curbs varies from \$2.50 to \$3.50, according to the depth of the well; with steel curbs the costs average 50 per cent more.

Suction Pumps. — There are several forms of suction pumps, the most common of which is the familiar "pitcher pump," so named from the resemblance to a pitcher suggested by its shape (Figs. 51, 52). Theoretically it will lift a column of water equal in weight to the atmospheric pressure, or about 32 feet, but in practice it is difficult to lift water by a pump of this type if it lies more than 25 feet below the cylinder. Its effective range can be increased, however, by sinking the pump cylinder below the surface of the ground. When the depth of the water is only 30 or 35 feet from the surface the cylinder is often placed at the bottom of

an excavated pit from 5 to 10 feet in depth, afterwards filled in or covered by a platform to prevent freezing. When the water is

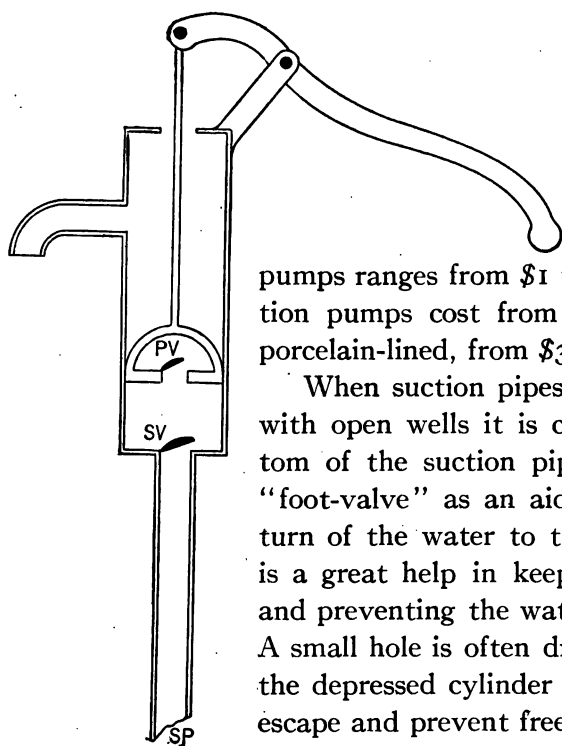


FIG. 51. — Diagram of suction pump. S P, suction pipe; S V, suction valve; P V, plunger valve.

at greater depths the pump cylinder must be lowered inside the outer casing until within working distance of the supply. The price of pitcher

pumps ranges from \$1 to \$2.50. Wooden suction pumps cost from \$2.75 to \$3.25, or, if porcelain-lined, from \$3.25 to \$4.00.

When suction pipes are used in connection with open wells it is common to fit the bottom of the suction pipe with a strainer and "foot-valve" as an aid in preventing the return of the water to the well. Such a valve is a great help in keeping the pump primed and preventing the water from "running off." A small hole is often drilled in the pipe above the depressed cylinder to permit the water to escape and prevent freezing.

A special form of pump, provided with an air chamber inserted between the pump-cylinder and the well, is used when the suction pipe is very long for the purpose of lessening the strains.

Deep Well Pumps. — The term deep well pump is commonly applied to any form of pump used when the water is below suction depth (Fig. 53). In the smaller wells, which are usually of the driven type and about 2 inches in diameter, a valve is set in the pipe just above the screen and below water level, while the plunger works in the casing itself immediately above the valve (Fig. 54). In larger wells the pump-cylinder, with a suction pipe below and a delivery pipe above, is lowered inside the casing. At times this



FIG. 52. — Properly protected dug well with pitcher pump. (Photo by U. S. Geological Survey.)



FIG. 53. — Properly protected drilled well with deep well pump. (Photo by U. S. Geological Survey.)

is placed below the water level, but is frequently just above it (Fig. 54). In very deep wells the pump cylinders are placed below water at the maximum depth to which it is lowered by pumping and are heavy and strongly constructed to withstand the considerable strain placed upon them. Ordinary forms of deep well or lift pumps cost from \$3 to \$4 when operated by hand, and from \$3.50 to \$5.00 when fitted for operation by windmills.

Force Pumps. — Force pumps not only raise the water from the well, but lift it to tanks or other containers, often at considerable heights above the pump. There are many forms of force pumps, but they are all modifications either of the common suction or of the deep well pump. The chief difference from the shallow well pumps lies in the use of pipes running to elevated tanks in place of open spouts. This necessitates either a solid plunger or a stuffing box at

the top of the pump cylinder to prevent the escape of water, and in most cases an air chamber is attached to equalize the pressure, prevent strains and to give a continuous discharge. Simple forms of force pumps (often without air chamber) may be had from \$5 to \$6, if to be operated by hand, or from \$6.50 to \$10, if to be operated by windmills.

Two of the most common forms of force pumps are shown in Figs. 55 and 56.

In the common house force pump, where the lift is very slight, the air chamber is often omitted, and a valve provided to allow the water to escape or force it to a tank as desired.

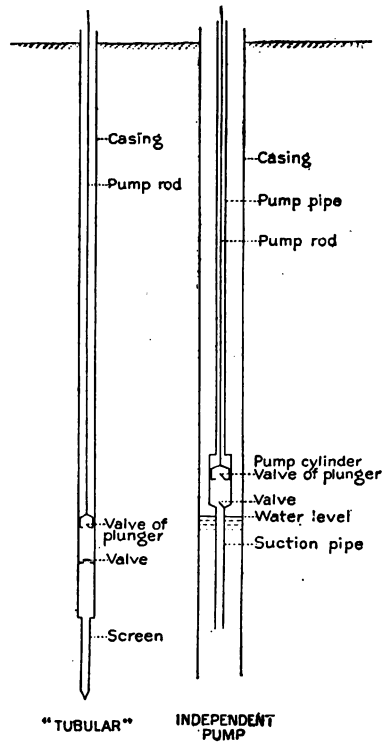


FIG. 54. — Common arrangements of deep well pumps.

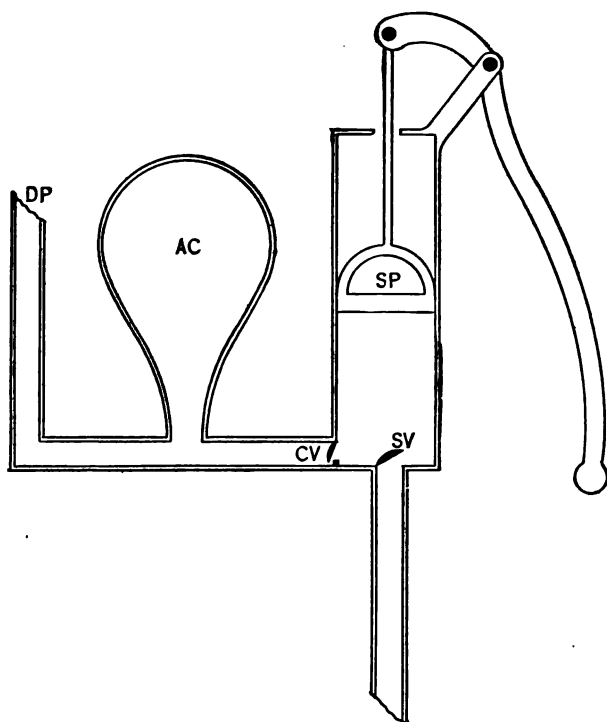


FIG. 55. — Common form of force pump. S P, solid plunger; S V, suction valve; C V, check valve; A C, air chamber; D P, discharge pipe.

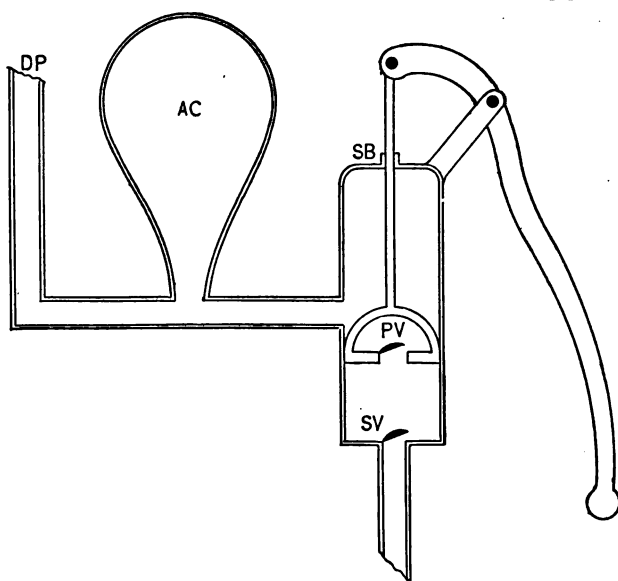


FIG. 56. — Common form of force pump. S V, suction valve; P V, plunger valve; S B, stuffing box; A C, air chamber; D P, discharge pipe.

The so-called siphon force pump, shown in Fig. 57, is used when the pump is not located over the source of supply, which may be from a well or river or other water-body from 100 to 500 feet away.

Rotary Pumps. — In rotary pumps the water is lifted by the suction of two revolving runners with blades rotating in opposite directions within a casing (the rotation being at the rate of 100 to 200 revolutions per minute), and forced by the same rotation to desired heights up to about 75 feet. Simple forms, lifting 15 to 40 gallons a minute, may be had at from \$7.50 to \$25.

Centrifugal Pumps. — These are somewhat similar to the rotary types, except there is only a single revolving runner. Inasmuch as the single runner will not at the start usually create sufficient vacuum to lift the water, this form of pump must first be primed. When the pump is working, the water, lifted by suction, is driven into a discharge pipe leading from the cylinder on a tangent. It is probably better adapted to pumping from trenches or streams than from wells, its great advantage being that sand, stones, and other débris of considerable size will pass through the pump without injuring it.

Air Lift. — This is a very efficient system of lifting water and deserves wider use than it now has. The method consists of forcing compressed air through a small pipe inserted within the casing. Emerging from the pipe at or near the bottom of the

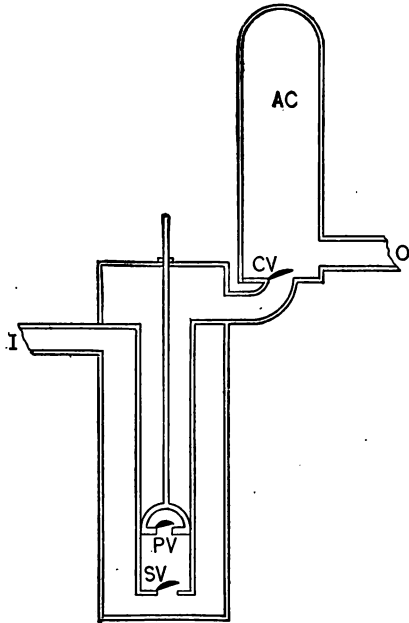


FIG. 57. — Siphon force pump; I, suction pipe; S V, suction valve; P V, plunger valve; A C, air chamber; C V, check valve; O, outlet or discharge pipe.

well, the only escape for the air is upward between the air-pipe and the casing. As it rises, the water is carried along with it and is forced out at the top of the well (Fig. 58).

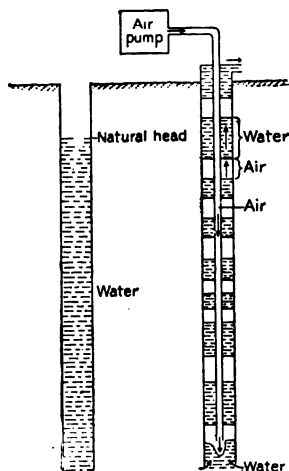


FIG. 58. — Diagram showing principle of air lift.

The effectiveness of the method is greatest when the water normally reaches within a few feet of the surface and decreases as the level of the water becomes lower. When the water in the well stands less than half way to the top, the air lift can not be used to advantage.

Hydraulic Rams. — While the methods of raising water previously described all require some form of power, either manual or mechanical, the hydraulic ram has the advantage of utilizing the water itself as its motive force. Its use, however, is necessarily limited to artesian wells of considerable head or to flowing wells or springs so situated that a material fall is available for operating the ram. In case of flowing wells the common practice is to connect the supply pipes leading to the rams directly with the casings; at springs the water is impounded in small reservoirs from which it is led through a strainer and supply pipe to the ram.

Only a few feet of head are necessary to operate such a ram, and if a sufficient supply is available it offers a very satisfactory means of raising the water. There is, however, always a very large loss. When the height to which the water is raised is only twice as great as the head, the efficiency may be as high as 86 per cent, but in raising it to higher points the efficiency rapidly decreases. When it is raised a distance equal to ten times the head the efficiency is only 54 per cent; when it is raised more than 25 times the height of the head the proportion of water pumped becomes small compared with that wasted. The wear and tear on the ram is also considerable when the head is over

10 feet. The ram, therefore, is most useful when operated with heads of less than 10 feet, and where the water is not to be raised more than 250 feet. Higher heads, however, than that indicated have been used with satisfactory results in some cases.

Given a flowing well or spring with a few feet of head and a moderate yield, this appliance can frequently be successfully used to lift an adequate supply of water to a house and barn at a considerably higher level. With 5 feet of head at the ram the water may be conveniently raised to about 30 feet, while with large rams and favorable conditions of head and volume water can be carried as much as half a mile and lifted 200 feet. The length of the supply pipe should be at least 30 or 40 feet to give the most efficient results. An actual test on a small ram costing \$9, with 70 feet of supply pipe and 12 feet of fall, showed that with 2.1 gallons per minute furnished to the ram, 0.3 gallon was delivered through 100 feet of pipe at a height of 50 feet above the ram. The only cost of operating is that of repairs.

Turbines. — Turbines, like rams, may be successfully used to lift a portion of the waters that operate them. Besides having a higher efficiency, which on experimental trial has been found to be as high as 80 per cent and can generally be depended upon to equal 75 per cent, the turbine has the advantage over the ram in not having to depend for its power upon the water which it is desirable to raise. Water power from a stream may be utilized to work a turbine, which, however, may lift not the water from the streams but from some other source, such as a deep well. Any fall up to 1,000 feet or more can be used to advantage and water may be drawn from any depth and raised to almost any desirable elevation.

Power for Pumping. — Windmills, gasoline engines, hot air engines, steam engines and electric motors are all successfully used in pumping water, but the situation of the farm and the relatively small volumes that are to be raised will commonly rule out all but the first two forms of power.

On large portions of the western plains, where the winds blow

fairly continuously and with some velocity, windmills are often a satisfactory source of power, although even here it is often necessary to provide large storage tanks or other reservoirs to tide over periods of calm or light winds. The windmill is most satisfactory when the water does not have to be lifted through any great height, and fails (because of insufficient power) in very deep wells when the water is far below the surface.

In most cases where windmills are inexpedient, gasoline engines will be found the most satisfactory source of power for pumping. Gasoline is fairly cheap, easily obtainable and highly efficient, while the fact that the engine may be started at a moment's notice whenever water is required makes its use second to none in convenience.



FIG. 59. — Windmill supplying water pocket. (Photo by U. S. Geological Survey.)



FIG. 60. — Artesian or flowing well. (Photo by U. S. Geological Survey.)

CHAPTER XVIII.

PECULIARITIES OF BEHAVIOR OF WELLS.

WELLS, although of almost infinite variety of type and construction, are seldom distinguished by any marked departure, either in characteristics or behavior, from the normal. Occasionally, however, they exhibit peculiarities of a striking and puzzling character. Among the most common of these anomalous phenomena are the fluctuations of head, the variation in yield of flowing wells with changes of weather, the roiliness of the waters during storms, the blowing, sucking and breathing of wells, and the freezing of the wells at points far below the surface.

Fluctuations of Head. — The ordinary variations of head, or the level to which the water rises in a well, depend on perfectly simple and well-known factors, such as variation in rainfall, melting of snow upon the surface, thawing of frozen ground, etc., all of which affect the supply of water penetrating the soil and reaching the wells. There is, however, another class of fluctuations of less frequent occurrence and of more obscure origin. In such fluctuations the water level rises and falls periodically, commonly standing lowest at about 10 A.M. and 9 P.M. and highest at about 3 A.M. and 4 P.M., but fluctuating much more widely during the passage of storms, the water rising on their approach and subsiding as they pass away. The daily variations are commonly under an inch, but the fluctuations marking the progress of storms often amount to several inches. Some wells that must be pumped during fair weather flow freely during storms.

Variations in Yield. — Where the head of the water in a tubular well is just sufficient to bring it to the top, the well is often very sensitive to changes of weather. A few wells flow at fixed hours, as at about 3 o'clock in the morning or at approximately 4 o'clock

in the afternoon, while a considerable number flow only during storms. Others, though flowing constantly, have their yield greatly augmented at such times, the effect being especially marked in wells of large diameter whose head is ordinarily barely sufficient to overflow the pipe. In such wells the discharge may be increased fifty or one hundred per cent or even more during the passage of marked weather disturbances. The increase of flow under such conditions is probably a universal phenomenon. though in copiously flowing wells of high head it is often inappreciable.

Roiliness of Well Waters. — Most wells normally yield clear water. In isolated cases, however, the water, which is ordinarily clear, becomes cloudy or milky on the approach of storms, and more rarely turns to a yellowish or reddish color under the same conditions. Examination shows the milkiness to be due to the presence of a slight amount of suspended silt or clay, and the yellow and red colors to fine particles of iron oxide held in suspension,

Blowing Wells. — Wells that emit currents of air from their mouths are called blowing wells. Blowing is not confined to drilled wells, but is noted in many dug wells, the air escaping through cracks or other openings in the covers. It was reported to the writer that the current passing out through the knot hole in the cover of one well was strong enough to lift a hat several feet into the air. At some times the whistling of the escaping air through the planks or pipes can be heard for several rods; at other times the current is strong enough to operate small whistles whose sound is loud enough to be heard for a mile or more in still weather. In some wells a dull roaring sound is heard as the air rushes through the casing; in other wells the air can be heard bubbling through the water.

Breathing Wells. — In most blowing wells the blowing is not continuous but alternates with sucking; such wells are more properly known as breathing wells. Probably most of the "barometer" or "weather" wells are of this class, although the indraft is usually less rapid and less conspicuous than the outdraft,

and in warm climates, where freezing never occurs, may be overlooked. Its presence is, however, abundantly demonstrated. Even if no indraft is observed, it is noted that the blowing is weak or ceases at times, so that there is a rhythm in the movement of the air. In humid regions the blowing is, as a rule, most marked before rain storms, and the sucking or indraft of air occurs in clearing weather after a storm. In other words, the blowing occurs during periods of low barometer and the indraft occurs in periods of high barometer. The blowing may be associated with some particular direction of the wind, as would be expected from the fact that the direction of the wind in rain storms is different from that prevailing in clear weather. Some wells show fluctuations with very small changes of barometric pressure, even with the diurnal changes, blowing at times of low pressure, as at 3 A.M. and 4 P.M., and sucking at times of high pressure at 10 A.M. and 9 P.M. In some wells there is a noticeable "lag" in the phenomena, the blowing and sucking continuing an hour or more after the limits indicated.

Sucking Wells. — Wells that suck in air at times are common, but those with continuous indrafts are very rare. Two such "sucking" wells have, however, been reported in Tertiary limestone near Boston, in southern Georgia. Where indraft alternates with outdraft the movement has a direct relation to barometric changes, but where the indraft is continuous no such relation is observed, the phenomena apparently being independent of barometric pressure. In the wells noted above the air is sucked in by streams of water running in caverns in the rock.

Freezing of Wells. — Throughout many of the Northern states much trouble is caused by the freezing of wells, not so much with the shallow dug wells as with the deeper drilled ones. Many wells in the North can be kept in use during the winter only with the greatest difficulty, so that the determination of the cause of the freezing and of means for its prevention is of great practical importance.

In open wells, including in this class the dug wells not provided with covers, the cold air — often many degrees below zero — is free to enter and displace the air of the wells, which, owing to its contact with the water and the unfrozen earth, is generally considerably warmer. Under such conditions, although the temperature of the entering air is somewhat modified by mixture with that already in the well and by contact with the walls, freezing often occurs at considerable depths, and the well is rendered useless during the continuance of cold weather.

In dug wells protected by covers there is generally little trouble from the freezing of the water unless it happens to stand very near the surface. Although few well coverings are tight enough to exclude the cold air, it penetrates so slowly that the temperature in the well, owing to the warmth given off by the earth and the ground water, seldom reaches the freezing point. In some wells, however, where open, water-free gravels occur above water level, much trouble is experienced.

In the simpler type of driven wells, consisting of a single continuous casing or of double tubes, both of which are carried below the ground-water level, little or no trouble is caused by the freezing of the water in the well, except, perhaps, when its level is very near the surface. The amount of cold air entering through the pump is insignificant, and there is no material circulation of air in the surrounding materials, and, therefore, no adequate cause for freezing.

Most of the wells subject to freezing are drilled or double-tube driven wells in which the inner or pump tube is carried below the outer casing, stopping in some porous stratum (Fig. 62), or wells drilled in limestone or other rocks that contain open solution passages (Fig. 64). The cause of freezing in these wells is discussed on pp. 138–139.

Pumps are certain to freeze if the cylinders are near the surface, as the water left in the valves and box after pumping freezes before it can drain back into the well. Where the cylinder is placed at a considerable depth, however, this difficulty is avoided,

except in what are known as the drilled wells, just noted. It is therefore a common practice to set the cylinder at as great a depth as possible and where practicable to surround it with tightly packed earth to shut out the air.

An investigation of the wells of Maine, a large part of which are in granites, slates, shales and other hard rocks that are free from openings, showed no instances of deep freezing. In Minnesota, North Dakota and Nebraska, on the other hand, large numbers of wells that penetrate porous deposits or cavernous limestones freeze every winter. In Wisconsin and Michigan freezing, though less common, occasionally occurs, especially in some of the wells in the porous gravelly hills and ridges. Even in Pennsylvania freezing, apparently due to the same causes, occurs in oil wells at depths of thousands of feet. In states farther south, especially in Iowa, Missouri, Kentucky and Indiana, wells occasionally freeze, both those in the porous surface deposits and those in limestones.

Cause of Phenomena. — The foregoing phenomena, including the fluctuations of head and flow, breathing, freezing, etc., are all found, on careful study, to be dependent on a single general cause. The relations to temperature and wind direction, with which the phenomena have been correlated by some, are found to be only casual. On the other hand, it is found that the peculiarities of behavior are very intimately connected with barometer changes, the relation of the blowing to storms being recognized by nearly every owner of a blowing well. Freezing, indraft of breathing wells, low water level, small discharge and clear water all occur in clear weather during periods of high barometer; while the thawing of the well, the melting of the surrounding snow, blowing, high head, strong discharge and milky or discolored water occur during periods of low barometer.

Since, in the breathing wells, the blowing is commonly associated with a falling barometer and the sucking with a rising barometer, it seems certain that they are caused by the variations of atmospheric pressure. The essential conditions, in most in-

stances, are that there be a double-tubed well, in which the air is able to pass between the pump-pipe and outer casing, and a porous, water-free stratum by which air may be absorbed or expelled according to the external barometric pressure. When, on the approach of a storm, the pressure at the surface is reduced, the air confined in the earth rushes out until equilibrium is re-established; but when, upon the return of fair weather, the pressure again increases, air is forced back through the well into the earth. In the few wells from which water is spouted during the period of "blowing," the casing probably extends virtually to the water, but not far below it.

The freezing of wells seems likewise to be due to the indraft of cold air at periods of high barometer, the air passing down the well and freezing the water. When, on a change of weather, the direction of the air current is reversed the well thaws and the snow about the well mouth melts.

The fluctuation of head and flow are also due to variation of atmospheric pressure. The water in many deep wells is under more or less hydrostatic pressure, which is opposed by the pressure of the air, the level at which the water stands representing the result or the balance of the two forces. If the pressure of the air is lessened and the hydrostatic pressure remains the same the water level in the well will rise, and if the atmospheric pressure increases the water level will fall. In some non-flowing wells the increased head will cause the water to flow; in flowing wells it increases the volume of discharge.

The roiliness of the water is apparently dependent on the same general causes, i.e., the fluctuation of barometer pressure. As low air pressure causes increased discharge in certain flowing wells, and as increased discharge produces increased velocity of the water both in the well and in the material from which the water is derived, it often happens, when this material includes more or less silt which is too coarse to be affected by ordinary currents, that quantities of silt are loosened under the increased velocity and taken up by the water, producing milkiness. Iron

oxide may be precipitated in the earth from chalybeate waters, although it may not ordinarily be present in amounts large enough to be noticeable in the water drawn from a well, but during periods of low barometer this oxide is disturbed in much the same way as is the silt, and mixes with the water as a yellow or red precipitate, rendering it unfit for use.

In wells that do not flow occasional turbidity is more difficult to explain, but the motion of the ground water tapped by these

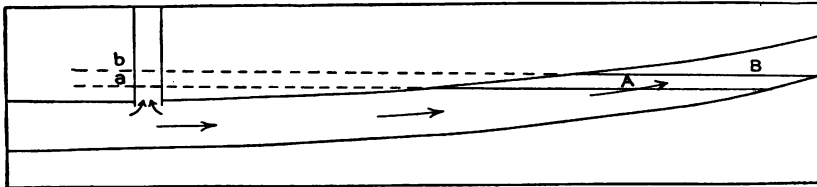


FIG. 61. — Supposed conditions producing discoloration of waters in non-flowing wells. *A*, normal water level in bed; *a*, normal water level in well; *B*, level in water bed during low barometer; *b*, level in well during low barometer. Arrows indicate direction of ground-water movement due to changes in barometric pressure resulting in disturbance of fine particles of clay or iron.

wells is no doubt caused by changes in barometric pressure and, as the phenomena occur under identically the same conditions, it is probable that they are due to the same general cause.

Remedies for Freezing Wells. — Several simple methods of preventing wells from freezing are in common use, but, owing to a failure to understand fully the causes of the freezing, many of these methods fail and others are only partly successful. Some persons have the idea that freezing is caused by the chilling of the air inside the well by the transmission of the cold outside air through the casing, to remedy which the pumps are carefully wrapped in cloth, packed with straw, or otherwise protected. As a rule, this protection is entirely without effect, for the freezing does not occur in the manner assumed, but by access of air to the pipe at considerable depths. Other persons partly recognize the true cause of freezing and make an attempt to prevent access of air by packing earth, straw or other material about the well. This practice is partly successful, as it tends to check the indraft

of air, but the materials used are as a rule so porous that more or less air gets through them and the well freezes. The use of manure is somewhat more effective, for it warms the air that passes through it, but it involves great danger of pollution.

Freezing is due to faults in the construction of the well itself and can ordinarily be prevented only by remedying the defects of construction.

In open wells the air obtains access through the soil at the junction of curb and cover and through cracks in the curb or in the cover. The junction of curb and cover is tight in but few wells, and the cover itself, if of wood, is tight in none. The remedy for freezing consists in substituting cement for wood and in tightly fitting it to the curb, which should also be coated with cement for some distance below the surface.

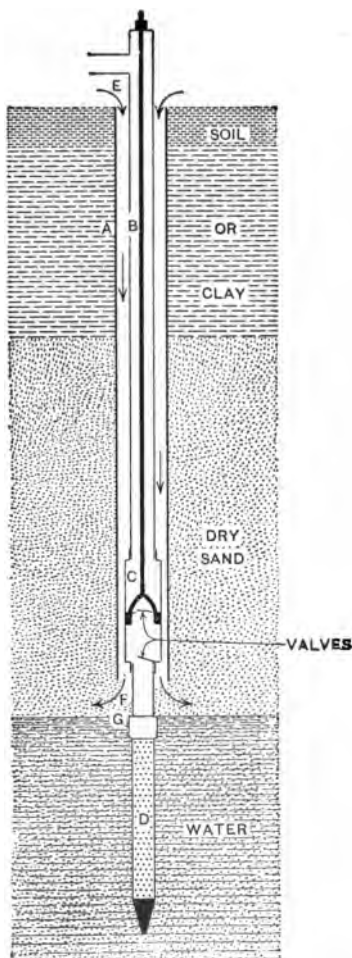


FIG. 62. — Conditions governing freezing in cased well with escape of air at bottom. (Sanford.)

The conditions in a cased well with escape at bottom are represented in Figure 62, in which A is the outer casing; B, the inner or pump tube; C, the pump cylinder; and D, the well point. When the barometer is high the air is sucked in at E, at the mouth of the well, and passes off into the unsaturated sand at F. If the well is not pumped, it will not freeze at first, as the pipe contains no water above the water level G. If the well is pumped and the water is raised to the cylinder C and up pipe B, the cold air passing between A and B is likely to freeze the well.

Even if the well is not pumped, the air current, if long continued, will eventually freeze the ground water at G and possibly also the water in the pipe.

The remedy for freezing in such a well is to fill tightly the space between A and B at a point near the surface with some impervious material. A filling of cement resting on an improvised plug will probably effectively prevent freezing. The home-made rag packing sometimes used is generally too porous, permitting enough air to get through to produce freezing. Rubber plugs are effective, but care should be taken not to use materials which can damage the water if they happen to drop to the bottom of the well. Manure should never be used about a well cased in the manner shown in the figure, as it can get to the water just as well as the air can.

Figure 63 shows a well which, though cased to a certain depth, has developed leaks by corrosion or imperfect joints and by careless setting of the casing in the rock. During periods of high barometer cold air enters the mouth of the well, passes downward between the casing and pump tube, and out into the porous stratum. The constant indraft of cold air quickly freezes the water remaining in the pipe after pumping.

The proper treatment is to plug effectually the space between the two pipes at a point near the surface.

The conditions in a well passing through porous rock are also illustrated in Figure 63, in which the bed of sandstone, although stiff enough to stand without casing, may be sufficiently porous to permit large amounts of chilled air to enter from the well during periods of high barometer, resulting in freezing, as before. The

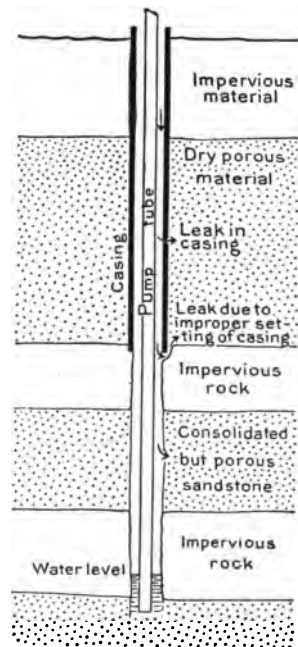


FIG. 63. — Conditions governing freezing in wells with leaky casings and porous walls.

remedy is a tight packing between the two pipes at a point near the surface.

Wells encountering open passages are practically limited to limestone in which solution channels have been formed by circulating waters and later abandoned. In Figure 64, which shows such a well, B is the pump tube and C an open passage into which air entering at the mouth of the well during periods of high pressure is carried off into the rock, producing a circulation which soon freezes water standing in the inner pipe. The treatment is the same as that required for the well just described; it consists of plugging the space at E.

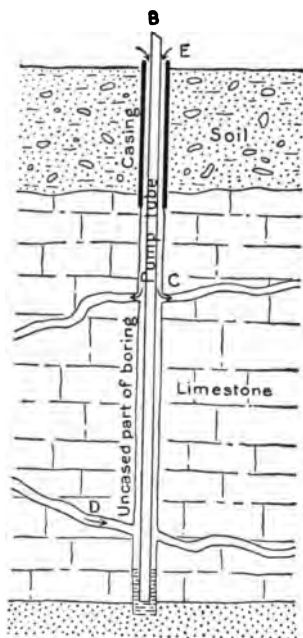


FIG. 64. — Conditions governing freezing in limestone wells.

In many wells, however, this treatment is ineffectual, indicating that the cold air is not entering at E, but is circulating through underground passages, as indicated by the arrow at D. In such wells it becomes necessary to set the plug at the point where the passage is encountered, in this case at D. In some wells, as in one near Wabasha, Minn.,

the crevices through which the air is circulating are so numerous that the space between the outer and inner tubes must be filled from bottom to top with cement.

CHAPTER XIX.

CISTERNS AND HOUSE TANKS.

When Cisterns are Desirable. — The ordinary cistern is an excavation in the ground, usually circular but sometimes rectangular, curbed with cement or with bricks, stone or other material (with a supposedly impervious lining of cement) and used for the storage of rain water. Wood-curbed cisterns are also occasionally encountered in frontier districts when other materials are not at hand.

Cisterns are desirable (1) wherever the rock, clay or other material is a poor water bearer; (2) wherever the ground water is too hard for washing, too alkaline for cooking or too brackish for drinking; (3) wherever waters from other sources are inherently unsafe; (4) whenever the ground waters are at depths prohibiting their common use; and (5) whenever the rainfall is too irregular to maintain a constant supply, or when wells, for one reason or another, are impracticable. They are especially desirable in the larger towns where the houses are crowded and the wells often polluted, and where no public supply is available. Again, on farms, where wells are not infrequently located near barns or other sources of pollution, cisterns often constitute the only safe source of water.

Advantages of Cisterns. — Perhaps the chief use of cisterns is to furnish supplementary supplies in regions where the available ground water is limited. In many of the best farming regions of the country, as in the Blue Grass region of Kentucky and elsewhere, the rocks either carry so little water or carry it so irregularly that many wells fail to obtain a sufficient supply to meet domestic needs and the demands of stock. In shaly regions the water supplies are even more uncertain and it is often impossible to procure

the necessary supplies from wells. This is true also of many areas underlain by clay and of some areas characterized by thick beds of clayey till. In all these regions supplementary supplies of water are necessary, at least for stock, and where springs, ponds or lakes are not available cisterns must be resorted to, and in some places they are necessary even for domestic supplies.

Rain water is the softest of all natural waters, hence is very desirable for washing and other domestic purposes, especially in limestone regions, where the water of many wells or springs is so hard that soap, instead of dissolving and making a good lather, forms a dirty-looking curd or scum on the surface. In such regions much trouble is also caused by the formation of thick crusts of lime and magnesia on the inside of the kettles and other utensils and by the precipitation of the white, milky sediment which clouds the water when it has been boiled. In other regions, as in parts of Florida and certain desert regions, the water may be highly charged with soda, with the result that rice or other white foods cooked in it are turned a dirty yellow. Elsewhere, especially on low sandy beaches and the keys of our limestone coasts, the well water is brackish and unfit for drinking. All these difficulties are avoided if soft cistern water derived from the collection of the rain water is available.

It is usually impossible for pollution to enter a properly constructed cistern—one in which the lining is water-tight—through the walls, and with a little care and by providing water-tight covers it is possible to keep out much of the undesirable matter from the top. Of course more or less dirt may be washed from the roof into the cistern, but the first run-off can be allowed to waste either by some automatic appliance or by hand, letting only the later and relatively pure water enter the cistern. A cistern, therefore, if properly made and cared for, is to be regarded as a practically safe source of supply. It is certainly far safer than the ordinary dug, bored and punched well, and even than many of the shallower driven wells.

Another great advantage of cisterns is their convenience. As

they are built near or even under a house, dairy or barn the water may often be pumped directly from them to the sink or to the dairy or watering trough.

Because of their shallowness and the smoothness of their walls, cisterns can be much more quickly and thoroughly cleaned than wells. Consequently they are usually cleaned more frequently and the water is kept in better condition.

Disadvantages of Cisterns. — Cisterns, notwithstanding their many good qualities, have some disadvantages. The dirt from the roofs is very objectionable, including dust blown from barnyards and highways, the droppings of birds, etc. The remedy is, as already stated, to allow only that portion of the water falling during the latter part of a shower, after the dirt from the roof has been largely removed, to enter the cistern.

Inasmuch as the cistern has to be emptied of its water before it can be cleaned, there must be some other available supply to tide over until it shall be again filled by the rains, but this disadvantage, of course, applies equally to wells.

The greatest disadvantage of a cistern and one which subjects the users to grave danger is the liability to crack. No matter how good the cement used in the construction or how careful the workmanship, cracks are liable to develop and admit shallow and possibly polluted ground waters. It is to the waters entering in this way that the notable hardness often indicated in cistern waters is due. Cistern water under normal conditions is soft, and if it becomes hard it is a sure indication that ground water has in some way found access to the cistern. It is a danger signal which should not be disregarded, and whenever it is noted the cistern should be emptied and repaired at once.

Size of Cistern Required. — The ordinary cistern, usually 5 or 6 feet in width and 10 or 12 feet deep, almost invariably fails to meet the demands on it during extended periods of drought. To insure a supply which can always be depended on either for domestic or for stock use, much larger cisterns or one or more reserve cisterns are necessary.

If rainfall were equally distributed throughout the year and if the consumption of water were regular, a cistern large enough to hold one or two months' supply would be sufficient, but, unfortunately, the rainfall is ordinarily very irregular, from one-half to two-thirds of the entire precipitation of the year not infrequently falling in three or four of the colder months, while the remainder is distributed over the eight or nine warmer months. This reason alone would make large cisterns desirable, but still another reason is found in the larger consumption of water in the warmer season, which is generally the period of deficient rainfall. To be sure of a supply through long periods of drought such as are likely to occur one or more times in each decade, it is necessary to have a cistern that will hold when full two-thirds or three-fourths of the total amount required during the year. For drinking, cooking and washing each person on a farm ordinarily uses from 5 to 10 gallons or more of water a day, and each head of stock ordinarily requires from 6 to 15 gallons. The amount used however, depends so largely on local conditions that it should be carefully ascertained in each specific case before the size of a cistern is determined. An allowance of 25 to 35 per cent should also be made for loss due to evaporation, the deflection of the earlier and more or less dirty washings from the roof, the overflow of gutters in heavy storms, the loss by snow sliding or blowing from the roof, the leakage of pipes and other minor causes. The total amount needed and the allowance for loss having been determined, it becomes possible to calculate the size of cistern or cisterns required. The volume of a round cistern is approximately five-sixths of the product obtained by multiplying the square of the diameter by the depth.

For assistance in determining the amount of water annually falling on a roof the following table, showing the number of gallons falling on each square foot on roofs of gentle, medium and steep slopes at different rates of rainfall, is presented. The annual rainfall of any particular locality can be ascertained from the United States Weather Bureau. (See also Fig. 1.)

Amount of water falling annually on roofs of varying slopes at different rates of rainfall.

Slope of roof.		Water falling on roof, in gallons per square foot, when annual rainfall, in inches, is:									
De- grees.	Ratio (ver- tical to hor- izontal).	15	20	25	30	35	40	45	50	55	60
45	1:1	6.6	8.8	11.0	13.2	15.4	17.6	19.8	22.0	24.2	26.4
26½	1:2	8.3	11.8	14.8	17.7	20.7	23.6	26.6	29.5	32.5	35.4
63½	2:1	4.2	5.6	7.0	8.3	9.7	11.1	12.5	13.9	15.3	16.7

Location of Cistern. — Theoretically the location of a cistern makes little difference in its liability to pollution, but practically it is of the greatest importance. As has been indicated, cracks in the walls are of common occurrence, in some cisterns being sufficiently open to admit enough outside water to make the supply noticeably hard, and where such water can enter pollution can enter also. Bacteria or disease germs can develop and enter the cistern through cement walls even when there are no cracks. It is therefore highly desirable that the cistern should not be located near a sewage drain, barnyard or other source of contamination, the same precautions being observed as have been indicated for wells. The site selected should be in firm ground, as otherwise there will be danger of the cistern settling and cracking. Roots of trees are also a frequent cause of injury, and cisterns should be located as far away from them as possible.

Construction and Equipment. — The excavation should be made large enough and deep enough to permit the laying of proper foundations and adequate walls. For curbing either cement or stone or brick laid in mortar and lined on the inside with a thick coating of hydraulic cement may be used. It is preferable that the top be arched over with brick or stone and lined with cement. An opening, provided with an air-tight cover, through which a person may enter the cistern for purposes of examination, cleaning and repair, should be left at the top. After the completion of the cistern, it should be frequently examined, in order to detect and remedy any cracks or other defects due to

settling, the action of frost, penetration of tree roots, etc. If there is any likelihood of the cistern filling to the top, an overflow pipe may be provided to advantage.

The use of wood-curbed cisterns, mentioned on p. 143, should be discouraged. Such cisterns not only commonly taste strongly of the wood, but they permit the entrance of both pollution and mineralized ground waters through their cracks, and are otherwise unsatisfactory in many ways. Care should also be taken with the equipment used for conducting the water to the reservoir. There should be adequate roof-gutters and leader pipes of galvanized iron or other non-rusting material to carry the water to the ground, while tiled pipes with cemented joints should be used to conduct the water through the ground from the house to the cistern. It is always desirable to provide a "leader cut-off," or "separator," which consists of a metal deflector — not very unlike the common dampers in stovepipes — which works within the leader. By means of this deflector the first more or less dirty wash from the roof is turned aside and carried out through an opening in the leader pipe, and it is only when the deflector — which is operated from the outside — is turned that the water passes into the cistern. There are also automatic appliances for accomplishing the same purpose.

Cistern Filters. — In addition to the deflectors, cut-offs, or other devices for separating the first more or less contaminated run-off from roofs, further attempts at purification are occasionally made by passing the roof-waters through filters before finally conducting them into the cisterns.

Sand and animal charcoal are the most effective of the various filtering materials commonly available to the farmer, and both are highly efficient filtrants when properly cared for. Unfortunately, however, unless frequently renewed (at least in part), they rapidly become contaminated both by the materials strained from the water and by the growth of bacteria, which develop with great rapidity within the filtering material as its pores become clogged. Water passing through a filter under these conditions

is likely to carry more bacteria and other forms of contamination than the unfiltered water.

Inasmuch as it is rare that the farmer possesses the time, to say nothing of the requisite knowledge and skill, to properly care for such mechanical filters, their use is of doubtful advisability, especially as the desired purification can be accomplished with greater facility and almost equal effectiveness by the use of automatic deflectors or similar devices.

Combination Wells and Cisterns. — Although cisterns of the dimensions indicated in the preceding section will supply enough water for domestic use in a small family, they will not supply enough for stock. In fact, unless the farm buildings are very large or numerous it is, as a rule, impracticable to procure enough cistern water to supply more than a few head of stock, and it is therefore generally necessary to utilize the ground-water supplies. These are sometimes too far from the surface to be available during the summer, but there is almost always enough water in the ground in winter, and the ideal provision would be to store a portion of the winter supply for summer use.

In the winter the ground-water level is high, often standing only a few feet below the surface, but in summer it is usually much lower, often many feet from the top of the ground. If a well is carried deep enough sufficient water can in most places be obtained, but many wells are too shallow to give never-failing supplies, and as a consequence they may be short of water in times of drought. If the water in the well in the winter could be retained till summer, there would be little difficulty with the supply of most wells, but, unfortunately, as the ground-water level falls the water in the wells falls also. In Fig. 65 *ac* indicates the depth of water in a well during the winter, and *bc* indicates its

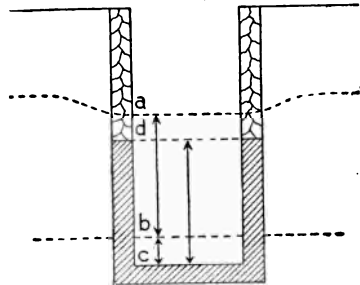


FIG. 65. — Combination well and cistern.

depth in the summer when the water level is at b . The volume at depth ac might be sufficient for the whole year, and that at depth bc insufficient to last through the summer. To preserve the winter supply it is necessary to cement the bottom and walls of the well nearly to the winter water level, as shown by the heavy lines in the figure, thus converting it into a semicistern. When this is done the well will fill during the winter to the level a and will still contain water to about the level d after the ground water has fallen to b .

Combination wells and cisterns of this type are especially dangerous if near any source of pollution, hence they are recommended only for stock wells located at some distance from buildings and barnyards. They should be used for domestic supplies only where on higher ground and at some distance from any source of pollution. Cisterns completely cemented and covered are safest where buildings are near.

In some places it is the practice to turn the water from buildings into a well, but, although the well water is somewhat softened thereby, there is no gain in amount, as water will not stand in an ordinary well higher than in the outside ground, the equivalent of the extra water turned into the well being lost by outward percolation.

House Tanks. — These are allied to cisterns but are constructed of wood with water-tight linings and are located within the buildings instead of in the ground outside. Inasmuch as they are filled by gravity it follows that they must be placed below the level of the gutters. The most common location is in an L or gable lower than the main building.

Such house tanks have the marked advantage of affording gravity supplies of flowing water on the lower floors. An automatic cut-off may be installed in the leader outside, or the deflector may be so arranged that it may be worked from inside the building.

CHAPTER XX.

FARM WATER-WORKS.

Convenience of Running Water. — It is the belief of many that one of the great evils of this country is the tendency of the young people of both sexes to remove from the farms. It is not simply that the glitter of the city calls, but partly that the dull routine and endless drudgery of rural life drives them away. Anything that serves to lessen the sordidness of the struggle, lighten the day's labor, or make less heavy the burden of life is of inestimable value.

In very few ways, if any, may the drudgery be so readily lessened or the pleasures and comforts of rural life so increased as by the installation of running water in the houses and barns. Everywhere this is beginning to be recognized, and the time should not be far distant when water-works systems will be found on every prosperous farm. That they are not there already is due to the facts that their great convenience is often not fully appreciated, that their nature is often not understood, and that their relative cheapness is not realized. The time is past when they are to be regarded as extravagances; to-day they are a necessity for both comfort and health. There are very few of the older or larger farms that cannot well afford the cost of their installation.

Time is money, and a water system furnishing a running supply is a labor-saving device that will quickly pay for itself when stock is to be watered, gardens are to be irrigated, or a house is to be supplied. To the woman, upon whom frequently falls the endless drudgery of pumping and carrying, in fair weather and foul, the water from a well located perhaps a hundred feet away, the relief afforded by the installation of such a system will be great. With

running water at the kitchen sink, with flush closets and bathrooms, and, perhaps, with a hot-water supply for washing, the life of every one on the farm will be made easier, pleasanter, and more healthful.

Methods of Supplying Running Water. — When the well, spring, or reservoir furnishing the farm water supply is situated considerably above the buildings to be supplied, and is not separated from them by intervening hills, the water may often be brought to the points of utilization by gravity. Unfortunately, however, the sources of supply are commonly lower than the buildings, and to make the water available at the latter some one of several forms of water-works systems must be installed. The systems in most common use are gravity systems supplied by elevated tanks and pneumatic systems delivering the water at the points desired through the agency of compressed air.

Gravity Supplies from Wells. — Where a flowing well is situated at a point higher than the building to be supplied, or where the head of the water is sufficient to lift it, when confined, to the desired point, the supply may be conducted to the house or barn by means of pipes attached directly to the well casing.

With tubular cased wells that do not flow, but in which the water stands at a point higher than that at which it is to be delivered, the pipe may be attached to the casing as before and laid to the house or barn. In dug wells, a pipe may be conducted from a point below the water level upward to the top and thence to the buildings as before. To start the water in the siphons thus formed, the air must first be withdrawn; usually this is most conveniently accomplished by attaching a suction pump to the lower ends of the service or discharge pipe.

The principle on which the siphon works is as follows: The pump temporarily attached to the lower end tends, when worked, to create a vacuum in the pipe, and the water, under the influence of the atmospheric pressure at the well, is forced upward until the pipe is filled. If the pump is now removed and the water allowed to discharge, the latter, by its own suction, will draw more

water from the well and a permanent circulation will be established.

Theoretically, water may be carried over a rise of more than 30 feet above its source, provided there is a still greater drop on the other side. In practice, however, 20 to 25 feet is about as high as it can be conveniently lifted. The chief difficulty arises from the development of small leaks which admit air into the pipe and destroy the vacuum. Also, more or less air is given up by the water itself in its passage through the pipe. This collects at the top of the bend and sooner or later the vacuum is destroyed. If lead pipe is used and the lift is not more than 15 feet, the siphon-age is seldom lost, but the farmer should never be without a pump or other means of reestablishing the flow. If tight taps are provided at the discharge end, the flow may be shut off when not needed and the waste of water thus prevented, but a leak may admit air and destroy the vacuum.

If the flow through a siphon is continuous, there will be comparatively little trouble from freezing and the pipe need not be buried more than a foot or two. If it is to be shut off when not in use, however, it should be placed at a depth of not less than 5 feet in the northern parts of the United States. Three feet is commonly a sufficient depth in the central portions of the country, and 2 feet or less for the southern portions.

The cost of galvanized iron pipe at the factory commonly ranges from about $3\frac{1}{2}$ cents a foot for $\frac{3}{8}$ -inch pipe to $5\frac{1}{2}$ cents for $\frac{3}{4}$ -inch, $7\frac{1}{2}$ cents for 1-inch, and 12 cents for $1\frac{1}{2}$ -inch.

Gravity Supplies from Springs. — To utilize the water of springs an impounding reservoir will usually have to be constructed. This may consist simply in stoning up the spring to hold back the surrounding earth, or it may require the construction of a small dam of earth or stone. In either case the labor is usually slight, requiring only a few hours or a day or two at the outside. A covering should also be provided to keep out animals and leaves or other dirt.

The service pipe should be placed far enough above the bottom

of the spring to prevent the entrance of sand or of matter that has sunk to the bottom, and low enough so the water level will not sink below it in times of drought, nor the strainer, with which it should always be provided, become clogged with matter floating on the surface.

The water may be carried to the house or barn by direct gravity service or by a siphon such as is described in the preceding section. The cost of pipe will be as there indicated, and the depth of burial about the same.

Gravity Supplies from Reservoirs. — Reservoirs may be either natural or artificial. If the latter, dams for impounding the water will have to be constructed. On the farm these will generally be of earth, with stone or cement flumes supplied with wooden flash boards. Masonry or cement dams are occasionally desirable for damming streams in narrow ravines with rock sides.

Earth dams should be built of clayey or loamy materials, should not be less than 8 or 10 feet wide at the top, and should have slopes not steeper than 35° or 40° , except when faced with stone. It is always best to strip the turf from the ground on which the dam is to rest and to dig a trench 3 feet or more in width, and 2 to 3 feet in depth along the center line. This should afterwards be filled with the material of which the dam is built or, better, with puddled clay, a core of which may be carried to advantage up through the center of the dam to the surface. It is always desirable to rest the dam on rock or firm materials, but, if this is not feasible, a low dam may often be made water-tight at the bottom by driving a center piling of slabs or boards.

The flume may be of wood, of stone set in cement, or entirely of cement. If the latter, the cement should be laid in temporary wooden frames or molds which should be removed as soon as the cement has set. A piling of boards or planks should be set beneath and for several feet each side of the flume, for these are common points of leakage and may, if not attended to, lead to the washing out of the flume or dam.

Much trouble in home-made dams is often caused by musk-

rats which dig through the dams in winter and give rise to leaks which, if undetected, may lead to the destruction of the dam. Stone and cement facings or core walls will prevent this. Usually there is little trouble from this cause where the inner face is given a gentle slope.

The method of piping will be essentially the same as described in connection with gravity supplies from wells and springs.

Gravity Supplies from Elevated Tanks. — In the case of elevated tanks, the distribution only is by gravity, some form of pump being required to lift the water to the storage receptacle.

Most of the tanks used in connection with farm water systems have one or the other of three forms: (1) Wooden, (2) metal, (3) cement. The wooden tanks are commonly of cypress with adjustable bands of iron; the metal tanks are usually of galvanized steel; while the cement tanks are of the best quality hydraulic cement with inclosed reinforcing irons.

The location of a tank will depend principally upon the material of which it is constructed and the amount of water to be stored. A cement tank, because of the method of construction and weight, will have to be placed upon the ground, usually upon the crest of a hill or similar elevation. A small wooden or steel tank may be placed within the frame of a windmill tower, or may be located in the upper story of a house or in the loft of a barn. Larger wooden and steel tanks naturally require special towers, either of wood or steel.

Cement tanks require considerable skill for their erection, especially in the insertion of the reinforcing iron, and their construction will seldom be desirable upon the farm. They are better adapted to the needs of small villages.

In placing a tank in a house or barn, care must be taken to see that the timbering is strong enough to support the load. The weight of the water is easily calculated by multiplying the capacity of the tank in gallons by $8\frac{1}{3}$ pounds. A 500-gallon tank, which weighs, when filled, about 2 tons, is about as large as it is safe to place within a house, although larger ones may be safely

installed in heavily timbered barns. The tank should always, if possible, be placed above a partition or other source of support to the floor. By using a large but shallow tank, the weight is more widely distributed, permitting larger supplies to be stored. Under such conditions, rectangular tanks are necessarily more convenient than round types. Sometimes a reserve tank is located in the cellar, the water being pumped to the higher tank as the demand arises. Such tanks may be filled with rain water (see House-tanks, page 150), but are more commonly supplied by pumping from a well or spring. Tanks in barns are conveniently filled by means of windmills located on the roof above them.

The location of a tank within a house or barn materially reduces the danger of freezing. The tank may be easily surrounded by straw or other insulating material, while the pipes are kept warm by the heat of the stoves within the house, or, to a certain extent, by the warmth of the stock quartered in the barn. It will usually be desirable, however, to have the pump located in a dry well, covered to keep out the cold air, and to bury the pipes below the winter frost line.

Exposed tanks give much trouble in northern latitudes owing to the tendency of the piping to freeze. Some relief is afforded by wrapping the pipes with several layers of insulating material and inclosing the whole in a box, but this does not prevent freezing within the tank itself. By shutting off the water at the tank and draining the pipes most of the trouble may be prevented, but, inasmuch as this involves climbing the tank, perhaps several times a day, it is rather a heroic and burdensome process during the long cold winters of the North. In cold climates the whole system, tank, tower, engine and pump, may have to be housed and kept warm by fires.

The size of a tank will be determined principally by the number of people and head of cattle to be supplied, but will vary somewhat with the conditions of filling. If a gasoline or similar engine is used, a tank that will hold a day's supply will often be

sufficient, but if dependence is to be placed upon a windmill the tank should be of a capacity to tide over a week of still weather.

The amount of water required for each person on a farm, including the water used for drinking, cooking and washing, is commonly placed at 10 gallons, but, if water-closets and bathrooms have been installed, the amount is likely to be nearer 25 gallons. Each horse or cow consumes about 10 gallons, each pig 2 gallons and each sheep about 1 gallon. A large farm will hardly get along with less than 500 gallons daily, while in some cases the amount used reaches a total of several thousand gallons.

Each foot of elevation above a water tap would give about half a pound of pressure if it were not for the loss of head due to pipe friction. This amounts to considerable in the case of moderate flows through small pipes. For instance, water flowing at the rate of 5 gallons a minute through a $\frac{3}{4}$ -inch pipe (inside diameter) loses $3\frac{1}{2}$ pounds of pressure (equivalent to a head of about 6 feet) for each 100 feet of pipe. A 1-inch pipe loses about 0.8 pound, a $1\frac{1}{2}$ -inch pipe $\frac{1}{8}$ pound, and a 2-inch pipe $\frac{1}{10}$ pound of pressure for each 100 feet of pipe when the water is flowing at the same rate. It is evident that pipe friction must be taken carefully into account when the height of a tank intended for supplying given buildings is to be determined.

The makers' prices for wooden (cypress) tanks are approximately \$5.50 for a tank of 175-gallon capacity, \$12 for one of 600 gallons, \$20 for 1000 gallons, and \$28 for one holding 2000 gallons. Steel tanks of the same capacity cost respectively about \$5, \$11, \$17 and \$26. A 20-foot steel tower to hold a 1000-gallon tank will cost about \$40, or, if 40 feet high, about \$75. The tower for a 2500-gallon tank should cost about \$65 if 20 feet high, or about \$125 if 40 feet high. The cost of pipes has been already indicated.

Pneumatic or Pressure Tanks. — These are vertical or horizontal tanks of varying capacity, into which, after the outlets have been closed, water is pumped from a well or other source of supply. As the water rises the air is compressed, the pressure increasing to 1, 2 and 3 atmospheres as the air is compressed to $\frac{1}{2}$, $\frac{1}{3}$ and $\frac{1}{4}$

its original volume. These pressures are equivalent to approximately 15, 30 and 45 pounds, respectively, and will lift the water, when the outlet valves are open, to 34, 69 and 103 feet. In other words, each pound of pressure, as shown on the gage, will raise the water about 2.3 feet. From these figures and the known elevation of the highest tap in use, it is easy to compute the pressure that will be required to distribute the water.

It is always necessary to carry a certain amount of excess pressure so that the system will continue to deliver supplies until the tank is fully emptied. Ten pounds of such excess pressure is usually sufficient in the case of an ordinary farmhouse. Considerable volumes of air are absorbed by water, especially under pressure, and the supply in the pneumatic tank is soon depleted. New air then has to be pumped into the tank, preferably when it is nearly empty.

In a recent form of the pneumatic system the air is forced into the tank by a hand or power compressor and thence by a pipe to a submerged pump at the well. As soon as any water is drawn from the system at the house or elsewhere the pump is automatically started by the compressed air and the water forced to the house and tap, thus giving a constant supply of water fresh from the well.

The size of the pressure tanks may be computed from the data in the preceding section, it being borne in mind, however, that the tank is rarely filled to more than two-thirds its full capacity. In locating the tank, the chief essential is to select a spot where it will be protected from the frost. It may be placed in the cellar of the house, in the stable, or beneath the ground. The cellar, if the house is provided with one, will probably be the most convenient location, since the tank will always be open to quick and convenient inspection.

The pneumatic system has many advantages over other systems, and, although it has been in practical use less than twenty years, it is already found in hundreds if not thousands of localities. It provides a system simple in operation and one in

which there is no possibility of contamination by dust and insects. If properly located, the system is free from freezing troubles in winter, while giving a cool, aërated and palatable supply in summer. There is slight danger of collapse and little trouble with leakage. Moreover, it is a flexible system and can be extended to supply other and higher fixtures by simply increasing the pressure.

The cost of a pneumatic system varies with its capacity and the power used. A 220-gallon tank of a working capacity of 150 gallons with equipment, including hand pump and fixtures, can be had for about \$60, but larger tanks cost considerably more. Although the original outlay is greater than for elevated tanks, the pneumatic tanks will last much longer, require fewer repairs, and demand relatively little attention.

CHAPTER XXI.

COMPOSITION AND TESTING OF WELL WATERS.

Purity of Rain Water. — Rain, which is the ultimate source of practically all waters reached by wells, is essentially pure when it falls upon the surface. Although it is true that a certain amount of dust and minute quantities of gas, including carbonic, sulphuric and nitric acid, are absorbed in the vicinity of cities by the rain drops in falling, and that near the sea a small amount of salt is brought down with the rain, the amount is very small. The gas in a cubic foot of rain water would hardly fill a half-inch cube, while the amount of mineral matter is insignificant compared to that dissolved in the passage of the water through the soil and rocks, and is, for the most part, negligible. Bacteria in rain are few in number and commonly of harmless types.

Source of Mineralization. — As the rain falls on the surface it commonly, in all but desert regions, sinks through a thin layer of humus or vegetable mould where it becomes charged with certain organic acids. These, together with the gases previously absorbed from the air, attack certain of the minerals with which they are brought in contact. The feldspars, which are components of granite and several other rocks, afford sodium and potassium; calcium and magnesium are obtained from many minerals and rocks, especially from limestone; while iron, aluminum and silica are derived from a variety of sources. Most of the substances mentioned are in the form of carbonates, sulphates, nitrates or chlorides. Many other substances, including some rare elements, are present in ground waters in small amounts.

The amount of mineral matter dissolved by the ground waters depends to a considerable extent upon the character of the materials through which the waters have passed. In sands

and gravels, where the grains are often nearly pure quartz (silica), only slight amounts of mineral matter are dissolved, some of the waters from such materials having only a few parts per million of dissolved solids. Elsewhere, however, where more soluble minerals are present, as in the alkaline or calcareous deposits of desert regions, the amount dissolved from sands and gravels is often very large.

In clays, because of the fineness of the grain, the water is brought into much more intimate contact with the material, and the amount of mineral matter dissolved is considerably greater, being usually several times as much as in sands and gravels. Many of the clay waters are decidedly alkaline or calcareous and are unpalatable and otherwise unfit either for drinking or for use in boilers.

In sandstones the waters are somewhat more mineralized than those of sands and gravels for the reason that the waters, owing to their slower movement, are in more intimate contact with the grains and remain longer in contact with the particles. Likewise, slate waters are usually more mineralized than those of their unconsolidated counterparts, the clays.

In crystalline rocks the mineral content of the water may be even less than in sandstone, since not only are rocks of this type relatively insoluble, but the water moves almost solely along open joints, etc., and is brought into intimate contact only with very limited surfaces.

In marly clays and in limestones the waters dissolve large amounts of lime and magnesium which give the water the peculiarity known as hardness. Many waters from the softer limestones carry the offensive sulphureted hydrogen gas and are known as sulphur waters.

Next to the composition of the water-bearing bed, time is the most important element in determining the amount of mineral matter in ground waters. The longer the water is in contact with the rocks the more mineral matter will be dissolved. As, in general, long periods of time are required, under the laws of cir-

culation, for waters to reach the deeper rocks, such waters will be almost invariably more mineralized than those at higher levels in the same rocks, although not necessarily more than in overlying rocks of more soluble materials. Likewise, as ground waters move more slowly through fine grained than through the more open and porous types, they will be more mineralized in the denser rocks.

Hardness of Well Waters. — As intimated above, hardness, which is the property of water which causes it to form an insoluble curd with soap rather than to give a frothy lather, is due largely to the presence of lime and magnesia, usually in the form of bicarbonates and sulphates. The water is said to possess temporary hardness when bicarbonates predominate, since upon boiling the bicarbonate is broken up, the lime precipitated, and the water softened. Where the mineral matter is in the form of sulphates, on the other hand, the water possesses permanent hardness since boiling has no softening effect. In general, water having more than 250 parts per million of hardness-producing constituents is inconvenient for washing purposes, although much harder waters may be used for drinking with impunity.

Water for Boilers. — Many of the waters that are satisfactory for drinking purposes are unfit for boiler purposes, owing to the fact that the mineral constituents are deposited on heating as incrustations on the inside of the boilers. There is no satisfactory way of determining the suitability of a water for boiler use other than by complete analyses.

In New England a purer water is demanded than almost anywhere else in the country. In the classification of supplies used by the railroads in locomotives, waters containing less than 4 grains of mineral matter per gallon (69 parts per million) are regarded as excellent, those of from 4 to 8 grains per gallon (69 to 138 parts per million) as good, those carrying from 8 to 12 grains per gallon (138 to 207 parts per million) as fair and those over the latter amount as unfit for boiler use.

In other parts of the country waters that are considered unfit

for use in portions of New England rank not only as "usable" but even as "good." Thus the Hartford Steam Boiler Inspection and Insurance Company, on the assumption that half of the total mineral matter present is in the form of incrustants, classes water containing up to about 15 grains per gallon (250 parts per million) as good, and that carrying from 15 to 30 grains per gallon (250 to 500 parts per million) as usable. In the West even more mineralized waters are frequently used in boilers.

Harmless and Harmful Ingredients. — The ordinary mineral ingredients in water, including lime, magnesia, silica, iron, etc., are usually harmless in the quantities in which they are commonly present, although slight digestive disorders are sometimes produced in susceptible persons on changing from soft to hard waters. Waters that carry salt or iron enough to be tasted, those that are strongly sulphurous and those which are charged with alkali are, however, unsuitable for domestic uses, although often used for such purposes. Occasionally waters are found that are high in magnesium sulphate (Epsom salts) or other "medicinal" salts, but it is needless to say that the habitual use of such waters is highly undesirable.

In general, waters that are without taste may be regarded as free from mineral matter in harmful amounts, but this is by no means true as regards bacteria and polluting matter. The clearest, coldest, most sparkling waters may be crowded with typhoid or other disease bacteria, and charged with seepage from cesspools and privies without the polluted condition being indicated in the slightest degree, either by taste or appearance. Ingredients of this character, though unapparent and often even unsuspected, are unwholesome and harmful, and render the use of the water highly dangerous.

When Well Waters Should be Suspected. — When well waters which are usually clear become roily, when any objectionable or unusual taste develops in previously tasteless waters or when an examination shows sources of pollution in the form of privies, cesspools, barns or hogpens within short distances — 150 feet or

less — of the well, the waters should be at once looked upon with suspicion.

It is true that the roiliness or turbidity may result from a disturbance of the soil at the very bottom of the well and be entirely harmless; but, on the other hand, it may be an indication of the entrance of polluted surface waters at the top. The cause should, in any case, be investigated.

The development of an unusual taste should likewise be looked into at once. Often, especially in driven and other tubular wells, the taste will be at once recognized as due to iron, and may be dismissed from the mind as harmless. At other times a woody taste is noticed. This may come from peaty matter in the soil and be unavoidable, but if from wooden curbing, these should be replaced by iron, stone or tile; for, although perhaps not always absolutely unsafe, decaying wood in contact with the water is far from desirable.

The most dangerous pollution is that coming from the discharges of man or animals, which seep through the ground from the privy, cesspool or barnyard into the well. It is by such pollution that the typhoid fever on the farm is frequently caused. Sickness does not result from the use of polluted waters in every instance, for the development of the more serious diseases requires the transmission of the specific disease bacteria in addition to the usual sewage bacteria accompanying filthy seepages. It is hardly necessary to say that, even when specific disease germs are absent, the use of polluted water, really a diluted form of sewage, is both obnoxious and risky.

Analyses and Bacteriological Examinations. — When there is any cause for suspecting pollution or for doubting the wholesomeness of a well water it is highly desirable that a sanitary examination of the water be made at once.

Pollution in well waters is commonly indicated by the presence of abnormal amounts of chlorine, usually derived from the urine of animals, by the presence of organic matter in the state of active decomposition, and by the presence of sewage bacteria.

The examination of the water will, therefore, usually consist of a determination of the chlorine (for comparison with unpolluted waters of the same locality), tests for nitrites and nitrates (indicative respectively of present and past organic decay) and bacteriological examinations.

The tests involved in the sanitary analyses and bacteriological examinations are quite delicate and to be wholly reliable must be made by competent specialists.

Almost every state has a laboratory for testing waters at the office of the state board of health, at the agricultural college or at the state university. Some private commercial laboratories also undertake the sanitary analysis of water, but, unless such a laboratory makes a speciality of water analysis, the results are likely to be of doubtful value. Many of the state laboratories, as well as the laboratories of the health boards of the cities, make no charge for the examinations, and, even when charges are made, the fees are usually moderate, seldom exceeding \$5 per sample.

Simple Sanitary Tests.—Although the sanitary examination of water should, whenever possible, be left to the trained analyst, there are a number of relatively simple tests affording some indication of the presence of pollution that may be made by the well-owner himself.

In the test for chlorine, the significance of which has been pointed out, a glass tumbler, previously thoroughly washed and rinsed in the water to be examined, is filled half full of the same. To this are added six drops of a solution (obtained from the druggist) made by dissolving five grains of nitrate of silver in an ounce of distilled water. If chlorine is present in appreciable amounts, a cloudiness or milkiness, which may be detected by holding against a dark surface, will be produced. Since, however, chlorine is an ingredient of common salt, which is normally present in slight amounts in most waters, a parallel test should be made with a near-by well or stream of known purity for comparison.

A rough test for organic matter may be made by adding to a bottle (previously washed and rinsed in the water to be tested), containing 8 ounces of the water, a teaspoonful of a solution (obtained from the druggist) made by dissolving two grains of permanganate of potash in an ounce of distilled water in a glass stoppered bottle. A half teaspoonful of a 25 per cent solution of chemically pure sulphuric acid, also kept in a glass stoppered bottle, is then added. The water, which should now be a bright pink, is to be allowed to stand for several days. If organic matter is present the solution will fade; if absent it will remain pink.

Another important test is that made for the nitrites, the presence of which indicates organic matter still in the process of decomposition, or, in other words, of recently added pollution. The average druggist will probably have to send away for the materials required in this test. Two solutions are first made up in a glass stoppered bottle: No. 1, made by dissolving 16 grains of sulpanillic acid in 10 ounces U.S.P. acetic acid; and No. 2, by dissolving 4 grains of *a*-naphthylamine in 10 ounces of U.S.P. acetic acid. To eight ounces of the water to be tested, add half a teaspoonful of solution No. 1, followed by the same amount of solution No. 2. Stir and allow to stand ten minutes. The presence of nitrites will be indicated by a rich pink color.

The determination of the presence of dangerous bacteria will usually require a laboratory examination. Certain forms of sewage bacteria may, however, be recognized, if present, by the following test. To a thoroughly washed and rinsed glass stoppered bottle holding about eight ounces of the water to be tested, add eight grains of granulated sugar and set in a warm place in the bright sunlight. If the bacteria are present, the solution should take on, within eight hours, a milkiness due to the presence of minute cells and strings of one of the sewage algæ.

Although the reactions outlined above may be given by substances other than those causing dangerous pollution, the fact that they are obtained is sufficient ground for looking on the

water with suspicion, and samples should be sent to a reliable laboratory for complete sanitary examination. In the meantime the water should be boiled before drinking, or before use for washing dishes and vegetables or in the preparation of uncooked food.

CHAPTER XXII.

PURIFICATION OF WATER SUPPLIES.

Necessity of Treating the Waters. — The process by which the pure waters falling upon the ground as rain gradually become mineralized in their passage through the soils and rocks has been described in the preceding chapter. The surface waters, supplied, as they are, chiefly from seepage from the ground, carry all the mineral matter dissolved by the ground waters, in addition to which there is soon added a certain amount of organic matter. Swampy waters often take on a deep brown color from the decaying leaves and wood, algæ frequently develop until the water is obnoxious both in odor and taste, while bacteria may multiply until the water is dangerous to health.

When such conditions arise, some method of reducing or removing the objectionable matter becomes imperative. Most of the substances, both mineral and organic, which give rise to the undesirable qualities may, fortunately, be removed or their effect neutralized by certain comparatively simple and relatively inexpensive methods of treatment. Several of the more common of such methods are described below.

Color. — By the color of a water is meant the appearance of the clear liquid. It should be distinguished from turbidity, or the appearance due to the presence of clay or other suspended matter. The color is usually the result of contact with the decaying vegetable matter of swamps, etc., and varies from a faint yellowish tinge to a deep amber or dark brown.

Water is decolorized to a certain extent when stored in reservoirs exposed to sunlight, which process is helped by aëration, but it is practically impossible to entirely remove the discoloration.

The discoloration of the waters of a spring can usually be prevented by cleaning the spring and carefully removing all leaves

and other vegetable matter which, by its decay, might discolor the water.

Turbidity. — Turbidity, due to the presence of suspended particles of sand, clay, etc., in the water, may be greatly lessened by storage for several days in a reservoir free from disturbing currents, but in the case of very muddy supplies the water never completely clears.

On the farm the use of any of the various types of filter beds is impracticable because of the expense and the skilled labor required for their proper operation. Much may be accomplished, however, by a careful application of the coagulation method.

It has been found that a sediment that will go through the finest filter may be removed by adding alum (aluminum sulphate), in the ratio of 1 grain of the chemical to each gallon of water (or one pound to 7000 gallons). In practice, it will be most convenient to calculate the volume of water in cubic feet and allow 1 ounce of the chemical for each 60 cubic feet. This treatment generally reduces the color in addition to removing the turbidity.

Odor and Taste. — In most instances, the odor and taste in surface waters are due to the presence of algous and other organisms of minute size. Aëration, such as that effected by spraying the water in the air for a few seconds, often accomplishes a considerable reduction of the objectionable smell and taste, but such treatment is seldom practicable on farms. The method giving most effective relief is the so-called copper-sulphate treatment used for removing algæ, as described in a subsequent paragraph.

Iron. — Iron, if present in objectionable amounts, is always recognizable by its taste. It is found in many well waters and frequently in those of springs, but, owing to the fact that it is commonly precipitated on contact with the air, it is not usually present in conspicuous amounts in surface waters. It may be precipitated by the addition of lime, and removed from the water by filtration.

Temporary Hardness. — Temporary hardness, so called from the fact that it may be removed by boiling, is due to the presence of the bicarbonate of lime in the water.

While boiling is effective in reducing the temporary hardness, its application will naturally be limited to families where the amount of water required is small. Where softening has to be conducted on a large scale, chemical treatment is the only satisfactory method.

To the water to be softened, lime water or milk of lime, made by dissolving commercial lime in water, is added. The lime reacts with the soluble bicarbonate of lime (to which the temporary hardness is due), forming an insoluble carbonate which is precipitated. About .8 pound of lime to 1000 gallons or 1 pound to 165 cubic feet is required when the water to be treated contains (as determined by chemical analysis) 10 grains of bicarbonate to the gallon. Proportional amounts will be required for waters with greater or smaller quantities of the bicarbonate.

Permanent Hardness. — Permanent hardness, or that which is not removed by boiling, is due mainly to the presence of the sulphates of lime or magnesia. It may be neutralized by the addition of soda-ash, or impure carbonate of soda. About 1 pound of soda-ash of 78 per cent strength or $1\frac{1}{2}$ pounds of 56 per cent strength are required to each 1000 gallons of water or each 135 cubic feet.

The chemical is usually added, after being dissolved and filtered, by mechanical appliances to the water of tanks or settling basins. By its action, the soluble sulphate of lime is converted into the insoluble carbonate and precipitated, leaving sodium sulphate in solution.

Alkalinity. — Certain well waters of the southern portion of the Atlantic Coastal Plain and many of the well and surface waters of the arid and semi-arid regions of the West contain considerable quantities of alkali, especially sodium carbonate, in solution. This gives to light colored vegetables cooked in such waters a yellowish color that is very objectionable, and,

if present in excessive amounts, renders the water unfit for drinking.

There is no entirely satisfactory method of treating these waters. A certain amount of relief is obtained in some cases, however, by adding calcium sulphate in the form of gypsum or plaster of Paris. This neutralizes, to a greater or less extent, the sodium carbonate giving rise to the objectionable alkalinity.

Algæ. — At times, the growth of algæ, including the so-called slimes as well as a number of more minute organisms, gives rise to highly objectionable odors and tastes in waters stored in ponds and reservoirs. Ground waters so stored often seem to be particularly susceptible to such growths.

Most of the organisms producing the objectionable features in the water are very sensitive to copper in solution, and by the use of the latter in amounts that, while fatal to the organisms, are harmless to those using the supply for drinking purposes, the odor and taste may be largely removed.

Copper sulphate is the compound used. About 1 ounce of the chemical is added to 30,000 gallons or 4000 cubic feet of water when the algaous growth is very pronounced; where slight, 1 ounce to 75,000 gallons or 10,000 cubic feet is sufficient. When the waters are high in carbonate of lime, more of the copper sulphate will be required, since a certain portion of the sulphate reacts with the carbonate.

The chemical is weighed, and then either placed in cloth bags and towed over the surface of the reservoir until dissolved, or it is dissolved in water and added through a perforated pipe at the inlet. Some time may be required to destroy the organisms, and a week may elapse before the dead algæ, which often have an offensive odor, settle to the bottom. For the latter reason, many persons consider the copper-sulphate treatment of more benefit if applied as a preventive before the algæ have formed than as a remedy after they have developed. Although not all the offensive organisms are killed and the process is, moreover, open to the other objections mentioned, it may be said that, in general,

a material improvement in odor and taste follows the application of the treatment. The cost is slight and the process easily and quickly applied, although a second treatment is sometimes required. With the possible exception of trout, fish are not likely to be affected by copper sulphate in the amounts used in the treatment.

Bacteria. — By far the greater part of the bacteria in water are of a harmless nature. Nevertheless water frequently becomes polluted with disease-producing bacteria, the removal of which is imperative if the supply is to be used for drinking purposes.

A treatment which has been applied with good results in many instances consists in adding chloride or hypochlorite of lime to the water. Both of these substances are powerful germicides, and 1 part of the chemical to 7000 parts of water will destroy practically all the bacteria present.

In practice, one pound is commonly used to each 33,000 gallons or 4500 cubic feet. It is dissolved and fed into the reservoir as in the copper-sulphate treatment. If thoroughly disseminated, it does its work within half an hour. The cost of the treatment is very slight.

The chief objection to the treatment lies in the fact that the chlorine set free in the process remains in solution and gives a very objectionable taste to the water. This, however, may be removed by drawing the water through a thin layer of iron turnings before use.

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